CULTIVATION PRACTICES,
MAIZE AND SOYBEAN PRODUCTIVITY AND SOIL PROPERTIES
ON FRAGILE SLOPES IN YUNNAN PROVINCE, CHINA

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This work or any part thereof has not previously been presented in any form to the University or to any other body whether for the purposes of assessment, publication or for any other purpose (unless previously indicated). Save for any express acknowledgements, references and/or bibliographies cited in this work, I confirm that the intellectual content of the work is the result of my own efforts and of no other person.

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Abstract

Sustainable agriculture in China is highly threatened by rapid urbanization, land degradation and high population pressure. Yunnan Province, south-west China, is 94% mountainous and lacks flat land. Food shortages and inappropriate cultivation have led to intensive cultivation of steep, marginal and fragile land and have increased soil erosion. To curb this situation and assist with poverty alleviation, it is crucial to develop more productive and sustainable cropping systems.

An experiment was conducted on sloping areas from 1999 to 2001 in Wang Jia Catchment, Yunnan Province. The project aim was to evaluate the effects of five selected cultivation practices on maize productivity and soil properties. The treatments were: (1) downslope cultivation without mulch, (2) contour cultivation without mulch, (3) contour cultivation with polythene mulch, (4) contour cultivation with polythene and wheat straw mulch (Integrated Contour with Plastic and Straw Mulch Treatment, INCOPLAST) and (5) contour cultivation with polythene mulch and intercropping, wide and narrow row spacing, with soybean in wide row spacing. Crop growth parameters and soil physical properties were measured throughout the cropping seasons.

Considering three years data, contour cultivation with polythene mulch generally increased soil temperature by a mean of 1-2°C. The polythene retained considerably more soil moisture during dry weather. However, during wet weather, polythene prevented rainfall directly falling on the soil, which led to less soil moisture content. The soil temperature and moisture regimes under polythene mulch made plants grow faster and canopies develop well, leading to higher final yields. The benefit of polythene was 33-54% more yield than downslope cultivation without mulch treatment, over three seasons. Contour cultivation plus polythene and straw mulch retained significantly higher soil moisture levels. The yield of this treatment in 1999 was ranked second, but in 2000 it had the highest yield and in 2001 it was also more effective than contour cultivation with polythene mulch treatment. Contour cultivation with polythene mulch and intercropping improved maize yield. The soybean harvest also contributed to net income, the crop had a similar function to straw mulch and increased N availability. Contour cultivation increased yields over the range 7.2-11.2% over

three seasons compared with downslope cultivation, equivalent to ~500-1000 kg per hectare more grain produced.

There were few clear trends in soil properties over the 1999-2001 period. However, N concentrations increased in the contour cultivation with polythene mulch and intercropping treatment. Both contour cultivation with polythene and straw mulch and contour cultivation with polythene mulch and intercropping gave apparent increases in total K, probably resulting from both decayed straw and decomposed soybean leaves.

In terms of simple cost-benefit evaluation, downslope cultivation had the lowest input and output, while contour cultivation had a similar input, but a higher output. Contour cultivation with polythene had the highest net return. Contour cultivation with polythene and straw had a high output but did not give a higher net return than contour cultivation with polythene. Contour cultivation with polythene mulch and intercropping generally had the highest input and output and could give a higher net return than contour cultivation with polythene when the soybean harvest was successful, but over three years this treatment had the greatest risk from crop failure.

It is recommended that replacing downslope cultivation with contour cultivation can increase crop yields and this simple action could contribute to the development of more sustainable cropping systems in Yunnan. Polythene mulch achieved higher maize yields but its environmental impact requires further study. It is considered that contour cultivation with polythene and straw mulch or soybean intercropping could contribute towards more productive and sustainable cropping systems where soil conservation is high priority. The technique could assist with long-term soil, water and nutrient conservation and improved crop productivity.

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Chapter 1. Introduction and literature review

General aim

This project aims to investigate the effects of selected cultivation practices on maize productivity and associated soil properties on sloping land in the highlands of Yunnan Province. Several practices effective in soil conservation have been identified as a result of detailed studies on erosion plots (Barton, 2000). These have been combined with practices designed to improve productivity, such as the use of polythene mulch. The research reported here evaluates some of the most effective practices under field conditions, using plots in a catchment managed by farmers in a local community. This project is part of a larger research programme (SHASEA (Sustainable Highland Agriculture in South East Asia)) which is developing a land management plan in a catchment in Yunnan Province, P.R. China. This catchment, Wang Jia (located north-east of Kunming), is in a mountainous region where fragile slopes are traditionally cultivated with arable crops. The management plan is designed to improve the productivity and sustainability of cropping systems in the catchment. The research reported here comprises the scientific evaluation of a range of cultivation practices which, if proved to be effective, will be incorporated into agronomic management plans.

1.1 Agriculture in China

China is a rapidly developing country with an area of 9.6 million square kilometres. It is the third largest country in the world, after Canada and Russia. The total population is 1,290 million which is the highest of any country and 22% of the world population. According to the data of the Second National Soil Investigation, 70% of land in China is mountains and hills, 29.64% is between 8-25° and 5.45% is >25° (Wang, 1992). More than 56% of the population reside in mountainous area (Wang, 1999). Unusable land, such as desert, glaciers, stone mountains and cold highland is >35%. The cultivated land area covers 131.1 million hectares, which represents 12% of national territory and occupies 7% of the world's arable land. Forest cover is only 16.5% (Fischer *et al.*, 1998).

In China, agriculture has over 7000 years of history (Cai, 1995) and it is the main national activity. Before 1990, the agricultural population was 84.6% (Chen, 1990). In 1998, about 75% of the labour force were engaged in agriculture and the livelihoods of most of the population depended on agriculture (Duan, 1999). How to produce enough food to satisfy the demand of 22% of the world population on a limited land resource is a major issue for national and local government, researchers and farmers. To achieve this, the general situation of Chinese agriculture and the challenges it forces must be understood.

Generally, north China has a continental climate growing suitable for wheat and maize and south China has a subtropical climate, suitable for growing rice and maize. The eastern coast is rich and urbanized, the centre is agricultural and less developed. The west is sparsely populated and mainly a pastoral area (Figure 1.1).

Figure 1.1. The general staple food and pasture distribution in China

(Source: China State Statistical Bureau, 1998).

1.1a Agricultural history of China from 1950 to present

Agriculture in China has changed dramatically since the 1950s. Before discussing the current problems faced by Chinese agriculture, the recent history of agriculture in China should be understood and can be outlined as follows.

1950- 1960: Arable land was redistributed by the peasants from the old landlords.

1956-1960: (communes: co-operatives amalgamated and the ‘Great Leap Forward’). During this period, land ownership was transferred to the commune level. Private land and markets were eliminated.

1965-1978 (search for alternative models). Land ownership was transferred from communes to villages. Local rural industry was encouraged, but also this reform was limited and productivity almost stagnated.

1978-Present day: (big success agriculture reform), arable land was leased to families (30 year contracts). The farmer was to fulfil a quota, but was free to choose producing crops and consume/sell the product, the free market was encouraged and this reform greatly improved production and efficiency. Even if agricultural productivity had increased significantly due to these reforms and advanced technology, several dilemmas remain. The challenges facing Chinese agriculture are outlined in the following section.

1.1b The challenges to China’s agriculture

China's grain production has been increasing steadily since 1950. From 1950-1990, total agricultural production increased dramatically and per capita increased from 239 to 390 kg. Until now, China's agricultural production has been able to meet population demands. Agricultural production increases have been due mainly to the enhanced use of hybrid seed, fertilizers and pesticide. However, these developments have led to serious long-term problems, particularly with regard to sustainability. Generally, the challenges facing Chinese agricultural sustainability can be summarized under the following headings. (1) Continuing population growth; this has been reduced by the ‘one child family’ strategies, but still remains a fundamental driving force. (2) Rapid industrialization and urbanization, which takes up more land and encourages labour movement away from land as a source of work. This provides more economic growth and cultural changes and provides the money to import food as an alternative to increasing population. This is also influenced by the national policy of self-sufficiency. (3) Environment pollution, both from agriculture (agrochemicals) and from industrialization and urbanization. (4) Environmental/Soil degradation, arising both from intensification, poor management and other pressures, such as changing workforce, mechanization, mining, road building and water management. Adverse climatic conditions, leading to desertification or salinization also contribute to these problems. Details are discussed in the following sections.

1.1.1 Population pressure on agriculture

In China, the population increased from 556.7 million in 1950 to 1,290 million in 2000 (China State Statistical Bureau, 2001), and the population was more than the combined population of Europe, the Americas and Japan. The trends were as following:

~14-17 million people were added each year in the 1980s.

~13 million people were added each year in the 1990s

~10 million people per year were added in the 2000s.

From this century, each year 10 million new people need to be fed, but traditional land structures have reached maximum capacity. The population census showed that there were 12×10^8 people in 1995, but total crop production is 4.65×10^8T (Qi, 1999). If one person needs 400 kg of food to consume each year, the food shortage is 1.25×10^6 T. Li and Lu (1998) also warned that China is a net grain importer and strongly depends on the world market, from 1977 to 1996, the grain imported was 244.53 million tonnes and just 101.94 million tonnes was exported. Thus, the net import was 142.59 million tonnes.

The Chinese government has recognized that poverty and environmental degradation have long been complex issues plaguing China's sustainable economic development. Though the impoverished population in China has decreased from 250 million in 1978 to 42 million in 1998, among those 42 million, approximately 20 million are living in extreme poverty and need more government assistance. More people mean limited living space and extra resource usage. With this swelling of resource absorption, tension between an increasing population and insufficient resources have become acute (China Daily, 2000). The intense poverty stems from the excessive exploitation of natural resources and serious environment degradation. The increasing population has put more stress on the environment. Excessive deforestation and unplanned construction are all spurred on by population growth.

Despite the slowing of China's population growth rate, owing to the family planning policy, China's population is still increasing. Therefore, the continued increase in population will put pressure to increase agricultural output.

1.1.2 Problems Brought by Urbanization and Industrialization

Urbanization, industrialization and road building have decreased agricultural land dramatically. Urbanization has developed very fast. The total urban population was 71.63 million in 1945 but by 1997 increased to 369.89 million (China State Statistical Bureau, 1998) and in 2000 more than 400 million live in cities and towns, some ~35% of the total population and this trend will increase sharply in the future. With the expanding urban population, more construction and road building and other facilities are needed and thus more fertile and flat arable land has been occupied. During 1988 to 1995, there were 980,243 hectares of flat land used for city/town construction (China State Statistical Bureau, 1997). Tillage land was reduced greatly, from 1986-1990, by 26.67×10^4 ha each year and from 1991-1994 by 33.3×10^4 ha per year (Qi, 1999). A high loss of land was also reflected in the land per capita statistics. The mean land per person in 1949 was 0.151 ha, in 1979 the tillage land per person was 0.104 ha (Chen, 1990), in 1990 it was 0.101 ha and in 1995 it was just 0.072 ha (Li, 1998). Moreover, China is a developing country that has achieved high economic growth and industrialization, which has led to rural-urban migration, as well as increasing use of natural resources.

1.1.3. Adverse Climate and Agriculture

China has a great diversity of climates, owing to its extensive territory and complex topography. Generally, in winter, the cold and dry climate is due to the prevailing winds from Siberia. In summer, a hot and rainy climate brings rain from the Southeast Pacific Ocean.

There are a range of differences in precipitation among different regions and rainfall is distributed unevenly. Agriculture suffers from different natural disasters and is affected by weather, mainly flood and drought, respectively. Some 60.6% and 25.1% of disasters were due to drought and flood, which influenced 45.6% and 18.1% of total arable land in 1978 to 1997 (China State Statistical Bureau, 1997). Also, due to global warming and the greenhouse effect, the temperature is expected to rise. The increase in temperature will be accompanied by more natural disasters and could induce some regions to have more droughts while others have more floods.

1.1.4 Land Degradation and Agriculture

Land degradation, erosion, depletion of soil organic matter and inadequate soil cover, are major agricultural problems. Land degradation and depletion of soil resources cause low crop production and incomes, increasing the risk of environmental damage.

Syers (1997) summarized the major types of global soil degradation. Erosion, which is accelerated by deforestation, overgrazing and mismanagement, affected $\sim 1028\times10^6$ ha. Chemical degradation was 147×10^6 ha, is mainly affected by salinization, acidification and pollution. Physical degradation accounted for 39×10^6 ha, affected by compaction, crusting and waterlogging. World losses of productive cropland due to soil erosion and associated degradation are estimated by FAO at 6-7 M ha/year (FAO, 1989).

Soil erosion is a major threat to the agricultural sustainability. Erosion is one of the main factors limiting and decreasing soil productivity on sloping land. Erosion by water removes topsoil and nutrients, reduces available water holding capacity and soil structural stability, causes surface sealing and reduces soil infiltrability (Rhoton and Tyler, 1990). Loss of 1 mm of surface soil can decrease crop yields ~10 kg ha^{-1}, decrease soil organic matter by 50% and decrease maize yield ~ 25% (Shi, 1991). One research study showed that 8-80% of N and 7-30% P was lost with eroded soil (Hubbard, 1983).

China is one of the more severely eroded countries in the world. Soil degradation has been extensive and the eroded area in China is 3.67 million km^2, some 38.2% of the total area (Wang and Wang, 2000). Soil loss is $>50\times10^9$ t, 20×10^9 t of soil are washed into the sea each year and total nitrogen, phosphorus and potassium loss is $\sim 0.4\times10^9$T. The resultant food loss is estimated to be $18\text{-}30\times10^9$ kg (Xue, 1995). The most serious erosion areas are in the middle-upper Yangtze River and the Yellow River. Sichuan and Yunnan Provinces are located in the upper Yangtze River basin. In 1999 remote sensing investigations showed that soil erosion over 22.27×10^4 km^2, some 45.9% of the total area of Sichuan, and has increased by 2×10^4 km^2 compared to the 1980s (Cai, 2000). In Yunnan, the total eroded area is 1.41×10^5 km^2 and occupies 36.88% of total area (Bureau of Yunnan Hydraulics, 2000).

Shi (1987) stated that about 0.3-0.5 cm of topsoil are lost annually in Yunnan and soil organic matter, nitrogen and phosphorus contents in eroded areas of Yunnan had decreased to 10, 5 and 2% of their original values, respectively (Shi, 1985). Whitmore *et al.* (1994) warned that accelerated soil and nutrient losses from Yunnan catchments might destabilize agricultural productivity and the agrarian economy over large areas of China. Plate 1.1 shows serious erosion in Yunnan.

Plate 1.1. Serious soil erosion during the rainy season in Yunnan Province

Soil from the Loess Plateau is the major source of sediment load in the lower reaches of the Yellow River. A sediment load of 16.4×10^9 t year was observed at the Sanmen Gorge. Some 25% of sediment load deposited along the riverbed in the lower reach causes an annual rise in the river of 8-10 cm (Sediment Speciality Committee of Chinese Water Resource Association, 1989). The Yellow River is called “an above ground river” (in Chinese: Di shang xuan he) that seriously threatens security. As the most severe soil and water loss area in the world, over 60% of land in the Loess Plateau has been subjected to serious soil loss, with an average annual soil loss of 200-2500 t/ha. Soil and water loss has seriously depleted land resources and degraded the eco-environment. Under normal conditions, land steeper than 25° should not be cultivated and should be covered by forest and grass, but in some areas of the Loess Plateau, slopes >45° are still under cultivation (Shi and Shao, 2000). Plate 1.2 shows the general view of the Loess Plateau.

Plate 1.2. General view of current Loess Plateau (Source:(SHASEA Research Team, 2002).

Erosion also occurs in other parts of China. Xia *et al.* (2001) found that 73.5% of sloping land was eroded in Liaoning Province (North China) and the total eroded area is 1.291×10^6 ha. The middle and heavy eroded area is 5.233×10^5 ha and 1.193×10^5 ha, respectively.

Soil erosion blocks rivers and creates serious problems. Each year more sediments sink in rivers and lakes. The five freshwater lakes in the Lower Yangtze River are an example (Table 1.1). In summer 1998, China was hit by the worst flooding for the century along the Yangtze River. Soil erosion resulting from deforestation, was a key factor contributing to the devastating floods and this was a bitter lesson for the Chinese people.

Table 1.1: The sediments of five freshwater lakes in the Lower Yangtze River (Source: Liu, 2001)

Lake	Sediments input (t/a)	Sediments output (t/a)	The net sediments in lake (t/a)
Dong Ting Lake	206,000,000	54,000,000	152,000,000
Bo Yang Lake	22,800,000	11,600,000	11,200,000
Hong Zhe Lake	17,500,000	10,300,000	7,200,000
Cao Lake	1,120,000	440,000	680,000
Tai Lake	440,000	100,000	340,000
Total	247,860,000	76,440,000	171,420,000

Pedological research found that most of the soil A and A+B horizons were moved by soil erosion in southern China and the soil tended to be rocky. Studies on granitic soils showed that runoff removes surface clay and makes soil shallow, worsens soil structure and sand content increases (Wan and Shi, 1991). Yu (1983) studied the pattern of soil micro-nutrient loss on the eroded middle Yellow River area and founds that most of trace nutrients were too low. One-third of land had a deficiency of Zn, B, Mo, Cu and Fe and half the land was deficient in Mn. From 1949 to 1995, the soil loss was 5000 million tonnes, nearly 3300 million t came from surface tillage land, lost N, P and K was 4 million t and food lost was estimated about 1800-3000 million kg (Xu, 1995). In Anhui Province, because of heavy soil erosion, the tillage soil thickness reduced by 3-5 cm over 30 years ago (Wang, 1992).

Although it is postulated that the nutrient loss in eroded soils could be replaced by chemical fertilizers (Mbagwu, 1984), studies show that physically degraded soils do not always respond well to chemical fertilizer inputs (Meyer, 1985). Soil erosion affects crop growth, through its impact on the soil moisture regime (Lal, 1987) and nutrient availability (Olson and Nizeyimana, 1988). Soil moisture governs the gaseous composition of soil air, and soil consistency, plasticity, strength, compactability, penetrability, stickiness, and trafficability (Hillel, 1982). Poor soil structure decreases infiltration capacity, increases run-off, reduces water availability to plants and lowers crop yields (Rhoton and Tyler, 1990; Mokma, 1992; Lal, 1995). Deforestation also accelerates soil erosion. Gao (1999) summarized the effects of deforest on soil erosion in the Yangtze basin (Table 1.2).

Table 1.2. Forest cover and soil erosion in the Yangze Basin

Year	Forest cover (%)	Erosion area (km^2)	Eroded area (%)
1957	22	363,800	20.2
1986	10	739,400	41.0

Desertification also seriously degrades agricultural land. Deserts and Desertified land cover 1.52 million km^2 of China, about 16% of its total area (Mitchell *et al.*, 1998). Land desertification has accelerated in recent years:

In the 1970s: the land desertification was 1560 km^2/a. In the 1980s: the value was 2100 km^2/a. In the1990s: the value was 2400 km^2/a.

In addition to the problems discussed, other problems are faced by China’s agriculture (Wang, 1992; Li, 1998; Xu and Mermoud, 2001).

(1) Mono-usage of land: because of food shortages, most sloping land has planted crops. Few farmers implement combined farming systems of grazing and forest and other practices, such as intercropping, crop rotation and manure inputs.
(2) The shortage of agricultural water and irrigation systems: the per capita water availability is too low, accounting for one-quarter of the world average value and is distributed unevenly. Some 60% of rainfall are concentrated in a very short season and are distributed unevenly. In Huang Huaihai, north-east and west China, this situation is more serious: tillage land occupies 63.7% of total tillage land, but the water just occupies 18% of total water volume, and is less on sloping land.
(3) Low agricultural productivity in related to the level of inputs.
(4) A low level of investments in agriculture.
(5) The middle-low fertilizer land is nearly 2/3 of the total tillage land and soil organic matter is low, having decreased by <1.5%.

From this review, it is apparent that soil degradation, especially erosion, directly or indirectly affects soil and crop productivity. It is an important limiting factor that threatens agricultural development in eroded areas. Therefore developing sustainable agriculture is crucial to eco-agricultural progress in China.

1.2 Prospects for Sustainable Agricultural Practices in China

Burton (1965) considered the invention of agriculture to have been one of three major technical revolutions for man's history, about 8000 B.C or earlier. Agriculture has contributed much to the development of civilisation. Nowadays, agriculture makes greater progress from the practice and experience passed from generation to generation. Farmers still search for novel systems. It is popular among agriculturists to identify particular approaches. In the 1960s and 1970s there was the 'green revolution' and then bio-dynamic agriculture (Keepf, 1976). This was followed by alternative agriculture (Board of Agriculture, 1989), Ecological Agriculture (Wu *et al.*, 1989) and Low input agriculture. (Stenholm and Waggoner, 1990). Recently there has been greater emphasis on sustainability.

Sustainable development has been extended to embrace living and non-living resources. It has been defined as development that provides economic, social and environmental benefits in the long term. Sustainable development is "*development that meets the need* *of the present without compromising the ability of future generations to meet their needs*" (World Commission on Environment and Development, 1987). A sustainable agricultural production system is defined as "*a dynamically stable and continuous production system that achieves a level of productivity satisfying prevailing needs and is adapted continuously to meet future pressing demands for increasing the carrying capacity of the resource base*." The above definition meets the conditions stipulated by Benbrook (1990) for a sustainable agricultural production system, including the avoidance of soil degradation and management of land and water to satisfy crop requirements.

China has started to adopt sustainable practices on its farms. Apart from protecting the environment, sustainable practices can also bring economical benefits to farmers. In the speech of Zhai Haohai (2000) at the 11th International Soil Conservation Organisation (ISCO) Conference, he pointed out the Chinese government is greatly concerned with ecological construction works towards water-soil conservation, and has taken a series of critical actions to step up the process. In 1991, the National People's Congress (NPC) promulgated the Law of the People's Republic of China on Water and Soil Conservation. In 1993, soil conservation was declared a fundamental national policy to be continuously pursued. It is a lifeline of development in mountainous area, a basis for land regulation and river harnessing and a foundation of national economic and social development. In the same year, the National Water and Soil Conservation Programme came into force. In 1994, China's Agenda 21 was formulated, in which measures on soil losses and desertification protection, as important components of a sustainable development strategy, were planned and arranged for. In 1998, the Government of China signed the UN Convention to Combat Desertification.

For more sustainable agriculture in China some of the widely recommended practices for sustainable agriculture are: (1) Intercropping and multiple cropping. (2) Organic manure application. (3) Conservation tillage. (4) Water-saving cultivation, and (5) Integrated agricultural management. For example, the government has begun promoting the use of integrated management on farmlands and practices such as water and soil conservation cultivation and low till agriculture. These have proved successful in increasing productivity in the USA. Low till farming has decreased the cost of farming and is a practical solution to some of China's agricultural problems. It is imperative to promote sustainable ways of increasing agricultural production which satisfy the demands of the increasing population.

1.3 Soil Conservation and Cultivation

Morgan (1986) and Schwab (1995) advocated similar grouping for conservative cultivation practices, especially for water and soil conservation, as follows:

1) Agronomic or biological: Use vegetation to control erosion (e.g. mulching, intercropping, rotation and agroforestry).

2) Soil management: Utilizing the soil resource to promote good structure, high resistance to erosive forces and suitable conditions for plant growth (e.g. organic matter applications, reduced or no tillage operations and application of soil conditioners).

3) Mechanical: Controlling the movement of water over the soil surface (e.g. terraces, waterways and contour cropping).

Lu (1995) pointed out that these measures can be integrated, so rainfall does not fall directly on sloping land. The major conservation cultivation techniques for annual crops are contour/ridge tillage, minimum/no tillage, mulching, Intercropping and rotation are also important for crop systems. Many studies have shown that conservation tillage practices were more effective in reducing runoff than conventional tillage (Römkens *et al.*, 1973; McGregor and Greer, 1982). Blevins *et al.* (1990) and Mostaghimi *et al.* (1988) demonstrated that conservation tillage reduces soil losses.

1.3.1. Contour/ridge cultivation

Tillage practices are needed to increase agronomic stability and productivity, while protecting the environment. Contour cultivation is a simple, effective and beneficial tillage method to conserve soil and water. It is a tillage method across the slope. Compared with conventional tillage (CK), runoff from contour tillage (CT) is minimized. The ridge tillage technique –developed from contour cultivation, but where crops are planted on the ridge or in the ditch, seems superior to contour tillage. Liu (1993) reported that compared with ordinary contour tillage, ridge tillage has a steady buffering effect on soil erosion and soluble nitrogen loss, even as slope increased. Zhang (1993) obtained similar results: ridge tillage can retain runoff, decease soil and nutrient loss, increase soil water utilization and further increase crops yields. Ridge tillage can also provide a favourable environmental impact. It was found that the combination of mechanical deep ploughing and ridge culture with plastic film mulching on the ridge, gave highest maize yields (Wang and Yue, 2000).

An experiment at Lanxi Soil and Water Conservation Station compared up-down slope ploughing and contour ploughing in terms of soil loss and soil nutrients (Li and Zhang, 2000). The slope degree was between 5-15º and the results showed that contour ploughing had a remarkable function for soil and water conservation in the maize field. The soil loss of up-down ploughing was 600 t km^{-2}, but contour ploughing was just 72.5 t km^{-2}. The nutrient loss from up-down ploughing was high, 121 kg km^{-2} N, 417 kg km^{-2} P and 1855 kg km^{-2} organic matter, respectively. However, contour ploughing reduced nutrient loss down to 16.2 kg km^{-2} N, 42.2 kg km^{-2} P and 243 kg km^{-2} organic matter, respectively. In the peanut field, soil loss of up-down ploughing was 2060 t km^{-2} and contour ploughing was just 690 t km^{-2}.

Cao (1994) found that conservation methods in Dingxi District, Gan Su Province in 1991 increased crop yields and conserved soil and water. The wheat yield of ridge and earth dyke tillage, furrow and ridge tillage, earth dyke with plastic film tillage, and straw cover tillage compared with contour tillage were increased by 8.8, 6.63, 9.74 and 19.32%, respectively. Flax yields were increased 40.54, 18.91, 48.38 and 75.66%, respectively. Potato yields were increased by 27.94, 25, 44.12 and 76.14%, respectively. All kinds of water conservation tillage measures collected run-off and intercepted soil. Straw cover tillage occupied the first place for gaining water conservation benefits.

In Central Croatia, Basic (2001) recorded soil erosion during 1995-1998. Five tillage methods were evaluated: 1) ploughing up down the slope to a depth 30 cm (PUDS). 2) no tillage, sowing with a special seeder into mulch up and down the slope (NT). 3) ploughing across the slope to a depth of 30 cm (PAS). 4) very deep ploughing across the slope to a depth of 60 cm (UDPAS) and 5)subsoil to a depth of 60 cm, subsoiler tines spaced 70 cm apart, with ploughing across the slope to a depth of 30 cm (SSPAS). The results showed that tillage across the slope (PAS, UDPAS and SSPAS) had less runoff and low erosion, which may be related to faster infiltration and slower runoff in these treatments.

An experiment was conducted at Zi Yang Soil and Water Station, Sichuan Province and evaluated the effects of different agricultural tillage practices on soil erosion and productivity between 1992 and 1993 (Zhang *et al.*, 2001). Results showed that contour cultivation deceased runoff and soil loss greatly compared with up-down cultivation, but the most effective and efficient way was ridge cultivation in combined with straw mulch (Table 1.3).

Table 1.3. Effect of different cultivation techniques on soil erosion and crop yields (each plots were 20×5m on an 8° slope) (Zhang *et al*., 2001)

Treatments	Soil loss (t/a .year^{-1})	Runoff (mm. year^{-1})	Yields*(kg/a .year^{-1})
Contour cultivation	5.46a	37.08a	8805.0
Ladder Ridge Cultivation*	1.72b	12.2b	9153
Ladder Ridge Cultivation With straw mulch	1.45b	13.86b	9480.0
Up-down Cultivation	16.88	86.3	

*The crop yield is the sum of wheat, maize and sweet potato.

*Ladder ridge Cultivation is the use of intercropping system, with wheat and maize planting with up-down ridge and then the sweet potato vertical interplanting into the space of the maize. The shape looks like a ladder.

1.3.2. Reduced /or no tillage

No till (NT)/minimum tillage crop production is widely applied across China, owing to its potential for reducing energy costs, labour saving and reducing soil erosion. It is a common conservation tillage system was which the soil is left undisturbed or disturbance is minimized. Many researchers advocate this technique. Jones and Popham (1997) and Unger (1994) reported that grain yields of dry land wheat and grain sorghum in the US Great Plains with NT generally equal or exceed those with stubble mulch tillage. Relatively short-term use of NT did not adversely affect soil physical conditions (Unger and Fulton, 1990). In the hilly drylands of Sichuan Province, Liu and Wang (2000) suggested that the seasonal no-till is the most effective cropping system for rain-fed agriculture. It consistently leads to less runoff over a range of soil types and slopes, the up-down tillage leads to more runoff and soil loss. Lal (1976) reported that no tillage and minimum tillage in conjunction with crop residue mulch improved soil quality and crop yield by increasing water infiltration into the soil profile and lessening water runoff and soil erosion. Minimum tillage practices are considered as an important component of sustainable rain-fed farming (Carter, 1994; Papendick and Parr, 1997). Compared to convention tillage, minimum tillage with 3 Mg ha^{-1} crop residue mulch proved to be a promising alternative soil management practice to improve and sustain higher yields of rain-fed maize and wheat in a sub-humid subtropical climate in the north-western Punjab, India, from 1993 to 1998. This practice also improved soil quality by increasing soil organic carbon, aggregation, infiltration rate and soil water retention, as well as decreasing bulk density near the soil surface (Ghuman and Sur, 2001). A study in Alberta, Canada, from 1994 to 1998 (Hao *et al.*, 2001) showed that surface soil under minimum tillage (MT) had significantly higher soil organic carbon (30.1 Mg ha^{-1}) content than under conventional tillage (CT) (28.3 Mg ha^{-1}). The MT treatment retained crop residue at the soil surface, reduced soil erosion and slowed soil organic matter decomposition, which are key factors in enhancing the soil fertility status of southern Alberta irrigated soils.

Other studies have not support the benefits of reduced/no tillage. Austin (1972) found that in reduced tillage systems, maize growth was generally poor during the early part of the growing season and lower yields are sometimes obtained. Ghidey (1998) found despite leaving most residues at the surface, no till did not reduce surface runoff compared to tillage systems that caused soil disturbance and buried residue. Thus long-term use of NT might impair soil physical conditions and yields. In other experiments maize yields were greatest with the CT (conventional mouldboard plough tillage) and CT-RC (conventional mouldboard plough tillage with red clover under-seeded in wheat) treatments. The NT treatment had the lowest yield, with a mean yield 13% lower than the CT treatment (Drury *et al.*, 1999). Richardson and King (1995) compared conventional tillage (CT) and zero tillage (ZT) farming system effects on sediment, N and P in surface runoff from watersheds with heavy clay soils in Central Texas, U.S.A, from 1985-1989. ZT had no effect on runoff volumes, but reduced the loss of sediment, N and P relative to CT. Crop yields were substantially reduced with ZT relative to CT. Most reduction was due to weeds on the ZT watersheds that were not adequately controlled with herbicides. The mean annual loss of soluble N was reduced ~50% with ZT relative to CT. The loss of N transported with the sediment was strongly dependent on tillage system, the mean annual loss of absorbed N for CT was 2.5 kg ha^{-1} compared with 0.3 kg $ha^{-1}$for ZT. Only small quantities of soluble P were lost, and there was no detectable effect of tillage system. Loss of absorbed P was small, but closely associated with sediment loss and significantly less from ZT than from CT. Therefore, the effects of no tillage are quite varied. In some areas, effective erosion control was achieved, while in other locations, runoff and/or soil loss were enhanced, thus negatively affecting crop yield.

1.3.3 Mulching

Mulches play an important role in sustainable agriculture and are used to protect the soil from erosion, conserve soil moisture, adjust soil temperature, suppress weed growth and often enhance crop yields. The mulches are divided into two materials: one is natural materials including compost, hay, wood chips, and nut shells and straw. Another is synthetic materials such as plastic film or paper mulch. Proper management of residues in cropping systems is essential to ensure sustainable production, and soil and water conservation (Smith, 1990; Rasmussen, 1991).

3.3.3.a Natural Mulch

Natural mulch for soil erosion reduction

Mulches can reduce surface sealing/crusting in soils with unstable aggregates, as energy from raindrop impact is dissipated. Mulches serve as physical barriers that dissipate erosive energy from raindrops, thereby protecting soil structure and thus improving soil permeability and reducing soil erosion. Crop stubble or residues buried in/over the soil after harvest help to control wind and water erosion and improves water conservation (McCalla 1961; Jones *et al.*, 1969; Fortin, 1993). Kwaad *et al.* (1998) found straw mulch was the most effective measure to reduce runoff and erosion by 46.5 and 89.5%, respectively, compared with the conventional system. On a 13.5° slope, soil losses from contour ridge tillage was 25.6 t/ha, but on the contour with straw mulch tillage it was just 5.7 t/ha and thus greatly decreased by straw mulch (Zhu *et al.*, 2000).

Effect of natural mulch on soil moisture and soil temperature

Plant growth and physical, chemical and microbiological processes in the soil are strongly influenced by temperature (Taylor and Jackson, 1986). Temperature is the main determinant of the rate of leaf appearance in plants (Cousens *et al.*, 1992), while photoperiod, rate of change of photoperiod and radiation level have been shown to be secondary (Baker *et al.*, 1980; Slafer and Rawson, 1997). Low soil temperatures can retard crop growth (Tisdale and Nelson, 1975). Schneider and Gupta (1985) pointed out that soil temperature in the seedbed is critical for rapid seed germination and emergence. Soil temperature exerts strong control over microbial activity (Nadelhoffer, *et al.* 1991; Ellert and Bettany, 1992; MacDonald *et al.*, 1995) and strong affects microbial respiration in soil (Edwards, 1975; Hendrickson, 1985; Tate *et al.*, 1993). Laboratory incubation of soils from northern hardwood forest at several sites in the U.S Great Lakes region demonstrated that microbial respiration was highly responsive to increasing temperature (MacDonald, 1995). Concentrations of organic C leached from soil was also affected by temperature (James and Riha, 1987; Duffy and Schreiber, 1990; Liechty, 1995), which suggested that losses of dissolved organic carbon from soils increases as a result of soil warming.

Growth is sensitive to water deficits and reductions in growth (mainly foliage) may occur at moderate soil water deficits, even if relative plant water content does not significantly change (Passioura, 1988; Kuang *et al.*, 1990; Gowing *et al.*, 1993; Keya, 1998). Acevedo (1971) demonstrated the importance of soil water in early maize development and showed in the laboratory study that elongation of intact young maize leaves was very sensitive to water supply, with relatively small changes in water status causing dramatic changes in growth. Hasset and Banwart (1992) confirmed that if soil was not sufficiently supplied with water, the rate of water movement to the roots would be reduced and less used by plants. Increased soil moisture is usually good for supporting crop growth. However, excessive moisture in poorly drained soils may promote some types of plant pathogens (Tisdale and Nelson, 1975).

The role of mulches and tillage practices in conserving soil moisture, with the subsequent effect on crop yields, has long been recognized (Grevers *et al.*, 1986; Gupta and Gupta, 1986; Sharma and Kharwara, 1990). Erenstein (1999) advocated crop residue mulching for improved resource conservation and productivity. Harrison and Lal (1979) reported that mulching delayed the onset of wilting for the maize by about five days during a period of water stress. Natural mulches may reduce soil moisture evaporation, through shading the soil, reducing weed growth and possibly reducing soil temperature increases due to solar radiation. Natural mulches generally tend to shield the soil from solar radiation. Since evaporation from the soil surface is reduced, soil moisture will be higher in a mulched soil. Because of the increased moisture content and reduction of incoming solar radiation energy, a mulched soil will also be cooler and the diurnal temperatures range will be lower.

Three years of field experiments were conducted on the effect of straw mulch and fertilizer on the utilization of soil water in hilly drought areas in west Henan (Li, 1994). The results showed that the effect of mulch on soil water conservation was significant in rainy seasons and mulch improved the availability of soil water in the upper 0-30 cm. The yields and water utilization efficiency of the crops were positively related to the amount of mulch, under drought conditions. Fertilizing could significantly improve the yields and water utilization efficiency of crops. Wu (1990) also demonstrated straw mulch improved soil water efficiency.

In semi-arid tropical regions mulch may be crucial in reducing the deleterious effects of intensive summer rainfall and may reduce high temperature injury to emerging seedlings by shading and slowing evaporation (McCown, 1996). In cooler areas early in the season, however, Berry *et al.* (1987) found residue cover increased soil temperature at 50 mm depth, and encouraged more rapid seeding emergence and development.

Shading by surface residue is most effective in reducing evaporation of soil moisture during the first-stage drying of a wet soil surface (Bond and Willis, 1970; Adama, 1976). Crop residue on the soil surface may also insulate the soil and retard early season soil warming, leading to lower plant densities and slower early development than on bare soils (Griffith *et al.*, 1973; Mock and Erbach, 1977; Fausey, 1984). Maintaining mulch on the soil surface retains water and insulates the soil surface, thereby reducing temperature extremes. The surface crop residues did not adversely affect crop emergence growth, or yield in sub-tropical environments. Organic mulches reduced afternoon soil temperatures and maintained higher soil moisture levels than other treatments (Schonbeck and Evanylo, 1998). Alice and Donald (1999) found that maize residue cover in no-till plots produced slightly lower spring soil temperatures.

Effect of natural mulch on soil fertility

If mulches are tilled into the soil before planting a new crop, they may affect soil fertility and soil chemistry. Crop residues on the soil surface have increased soil nutrients. For instances, Moody *et al.* (1952) observed increases in soil total N under a mulch tillage system in Virginia, USA. The increased N was mostly due to incorporation of more nitrogen from decaying straw mulch over consecutive seasons. Crop residue mulch also improved soil quality in terms of organic carbon and biotic activity (Karlen *et al.*, 1994). However, in the short term, mulches may decrease nitrogen availability to crops and a mulch material that has a high carbon content and is very low in nitrogen and other nutrients may actually immobilize plant-available nitrogen temporarily. This occurs because soil micro-organisms use available nitrogen to metabolize and decay the organic material. The immobilized organic nitrogen can be mineralized later as the organic matter continues to decompose. Cover crops are considered a tool in integrated weed management and control seasonal soil and nutrient losses in row-crop production (Altieri, 1988; Swanton and Weise, 1991).

Natural mulch and crop productivity

Tillage practices that maintain crop residue on the soil surface can increase maize yield (Triplett Jr *et al.*, 1968; Lal, 1974, 1995). Lal (1974) found that maize grain yields increased by ≤52% with mulch applied after planting. Gajri *et al.* (1994) found that mulching increased maize grain yields from crops in loamy sand in all the 10 years studied. Mulch increases in yield were also reported by Tolk *et al.* (1999), with grain yield increases induced of 17%, above-ground biomass by 19%, and grain water use efficiency by 14% compared with bare soil treatments in 1995. Mulch also helped reduce soil water evaporation, which benefited high water use crops, such as maize.

Christian *et al*. (1999) compared different straw residues in Oxfordshire. The treatments were: (1) straw burnt, (2) cut straw was removed by baling, leaving only the stubble and (3) straw chopped and evenly spread over the plot on winter cereal grown from 1979-1988. The results showed that the best yields of winter cereals were achieved when straw was burnt, irrespective of tillage. The results provided strong evidence that, in heavy clay soils in the UK, sowing cereals after shallow cultivation or by direct drilling in the presence of straw residues is unreliable and may restrict both early crop growth and yield. The causes of poor crop establishment were probably multiple and included poor seed burial and slug damage. Christian recommended ploughing to ≥15 cm depth to improve reliability in crop establishment, minimize the presence of volunteer cereals and to help maintain crop yield and product purity. Similar results have been reported (Ellis and Lynch, 1977; Oliphant, 1982; Lord, 1988).

An experiment was conducted in Henan Province to compare different straw mulch rates (12000, 7500, 5250 and 3000 kg/ha and no mulch) on soil water conservation and yield. The results showed that with increasing mulch rates, weed cover decreased and the mulch retained soil heat and increased crop yield (Hu, 1998).

3.3.3.b. Synthetic mulch

Plastic mulch, employing clear polythene sheeting may be used to increase soil temperature to allow for early planting or to encourage early seedling emergence. The plastic transmits short-wave solar radiation and then increases soil surface temperature through a 'greenhouse' effect, trapping outgoing long-wave radiation.

Many studies have demonstrated that plastic film greatly improves crop yields. In China, polythene cultivation was introduced from Japan in 1979 and this technique can increase crop yields (Wang and Wang, 1993). Sun (1990) showed the highest yields were on polythene mulch and terraced plots, the yields were 7861.0 and 7286.7 kg ha^{-1}, respectively. The lowest yield was on downslope cultivation, at 5416.6 kg ha^{-1}. Liu and Wang (2000) greed with this result, the yield of combination of mulching with plastic film and maize straw was 36-54.5% higher than no-mulch treatment.

A study of three different mulches was conducted in eight counties of Biji City, Guizhou Province. The results showed that the yields for potato straw mulch was 437.8 kg ha^{-1}, increasing 8.1% compared to bare fields. The yield for wheat mulch increased 11.8% compared to bare yields and polythene mulch increased 20.4-23.1% compared with bare fields (Xie, 2001).

Research involving straw and plastic mulching measures for maize was conducted in Luo Dian County from 1991-1992 (Tang, 1993). Results indicated that at the earlier growth stage of maize, straw mulching could reduce evaporation of water from the ploughed layer and intercepted more surface water than the plastic mulch. It also had, compared with bare land, an increase of 2.1-4.7% in soil water content and an earlier germination, and more even plant growth as well. Plastic mulching increased maize yield by 9.3-13.5% compared with bare soil.

Polythene mulch emerged superior in improving root growth compared with no-mulch applications. Wang and Zhong (1999) pointed out that the cultural technique of wheat sown in pits with the film can conserve soil moisture and increase soil temperature. In turn, this can increase yield, when sown at a suitable date, by >50%. Although plastic film promotes yields, the labour requirements for mulching and planting are greater for plastic than for organic mulch (Schonbeck and Evanylo, 1998) and plastic usually requires removal and disposal after harvest.

An experiment conducted in Lan Xi, Zhejiang Province, compared mulch effects on soil properties and maize growth (Lei, 1994). Polythene mulch increased soil temperature significantly compared to bare soil. Straw mulch had no significant effect on temperature, but both improved soil moisture and porosity. Polythene increased soil moisture and soil total porosity to 13.8 and 58.3% compared to 10.7 and 54.8% on bare soil, respectively. The soil bulk density decreased by 1.20 to 1.08 g cm^{-3}. Polythene mulch can promote maize germination, tasseling and silking and harvesting 2-3 days, 4-5 days and 6-7 days compared to bare treatments, respectively. Yields increased by 20.5% for polythene mulch compared with bare treatment and the straw mulch increased yields by 14.3% compared with the bare treatment (Lei, 1994).

A study compared polythene, straw and bare soil treatments on water-retention in Shan Dong Province (Zhang *et al.*, 2000). Results showed that polythene mulch can retain soil moisture greatly, followed by straw mulch, then bare soil. Polythene mulch increased soil temperature, but straw mulch had a reverse result (Zhang *et al.*, 2000).

Paper mulch is also used in a small scale, especially for grass planting. However, few farmers use paper mulch. Munn (1992) demonstrated that paper mulches were biodegradable and improved vegetable yields, reduced weed growth and conserved moisture, but there are few other published reports.

In West Virginia, studies compared recycling newspaper, non-mulched soil and a black plastic mulch and their effects on vegetable and small fruit crops (Selders *et al.*, 1994). Results showed both positive and negative effects depending on plant type. Paper mulch was credited with significant yield improvements for cucumber and bell pepper, but paper mulches did not increase strawberry yield. Higher tomato yields were occasionally observed, but yields differences were reduced in the absence of water stress.

A field study in Alabama investigated newsprint and nitrogen source interactions and their effects on maize growth and grain yield (Lu *et al.,* 1994). When the ground newsprint was applied to soil in combination with inorganic nitrogen sources (ammonium nitrate, urea and anhydrous ammonia), newsprint increased grain yield by 37% when poultry litter was applied as the nitrogen source; when anhydrous ammonia was applied as the nitrogen source, newsprint reduced grain yield by 78% (Lu *et al.*, 1994). Application of ground newsprint had no effect on grain yield when ammonium nitrate and urea were used as nitrogen sources.

1.3.4 Crop intercropping and rotation

1.3.4a Crop intercropping

Intercropping is a technique that uses two or more compatible crops planted effectively utilizing common resources, which maximize beneficial interactions while minimizing competition. Richards (1983) summarized the benefits of intercropping. These included: minimized soil erosion (especially if fast growing and slower-maturing varieties are planted together), minimized spread of pests and diseases, maximized use of available soil moisture, sunlight and plant, suppression of weeds and minimized risks of crop failure.

When two or more crops are grown together, each must have adequate space to maximize co-operation and minimize competition between the crops. To accomplish this involves consideration of spatial arrangement, plant density, crop maturity dates and plant architecture. The main spatial arrangements are as follows:

(1) Row intercropping: growing two or more crops simultaneously with at least one crop planted in rows.

(2) Strip intercropping: growing two or more crops together in strips wide enough to permit independent cultivation and close enough for the crops to interact agronomically.

(3) Mixed intercropping: growing two or more crops together in no distinct row arrangement.

(4) Relay intercropping: planting a second crop into a standing crop at a time when the standing crop is at its reproductive stage, but before harvesting.

Researchers have designed a method for assessing intercrop performance compared to pure stand yields: the Land Equivalency Ratio (LER). To calculate a LER, the intercrop yields are divided by the pure stand yields for each component crop in the intercrop. Then, these values are added together.

LER = (Intercropping crop 1/pure crop 1) + (intercropping crop 2/pure crop 2) + *etc.* Formula (1.1).

When an LER measures 1.0, it tells us that the amount of crop grown together is the same as that for crop grown in the pure stand, it means there was no advantage to intercropping over pure stands. LER >1.0 show an advantage for intercropping, while values <1.0 show a disadvantage for intercropping.

Many intercropping combinations of vegetables, crops, grasses and trees have been investigated. Throughout Central America, a common intercrop of maize, beans and squash is traditionally grown. Grown together, these three crops optimize available resources. The maize was high over the other two crops, while the beans climb up the maize stalks. The squash plants sprawl along the ground, capturing light that filters down through the canopy and shades the ground. The shading discourages weeds. In China most intercropping includes combinations of cucumbers, beans, maize, potato and groundnuts. Fu and Che (2000) recommended that farmland should be intercropped using different crops and grass fruit trees, which increases diversity and creates a more patchy landscape. In Fujian Province, the intercropping areas is 87% of total maize planting and maize is often intercropped with soybean, peanut and sweet potato (Department of Tillage and Rotation of Fujian Agricultural Academy, 1988).

Intercropping for reducing soil erosion and improving soil fertility

Contour hedgerow intercropping technology includes perennial woody nitrogen fixing plants planted very thickly along contours on sloping farming land as hedgerows with an inter hedgerow distance of 3-6 metres. The technique can reduce surface runoff by 50-70% and soil loss by 97-99% and increase soil organic matter (SOM) by 25-35%. The improved soil fertility and soil moisture condition enhanced crop yield by 30-60 % (Tang *et al.*, 2001).

In Yunnan, a field experiment by Liu and Wu (1991) tested the effects of maize intercropping with potato on soil erosion, soil nutrients and crop yield. The results showed that intercropping reduced runoff, soil losses, organic matter loss and the nutrients loss by 22.2, 56.4, 50.8 and 51.4%, respectively, compared to monoculture and the crop yield increased by 23.0%. One of the advantages of legumes with intercropping, over continuous monocropping, is nitrogen fixation. Bruulsema (1987) reported that legumes provided of 90-125 kg N ha^{-1} to the following maize crop.

In the Philippine uplands, hedgerow intercropping was compared to traditional open field maize farming (Nelson and Cramb, 1998). Results indicated that alternative forms of hedgerow intercropping, such as natural vegetation and grass strips, reduce establishment and maintenance costs and are therefore more economically attractive to farmers than hedgerow intercropping with shrub legumes. Hedgerow intercropping sustained yields at higher levels than open field farming in the long term, and significantly reduced soil loss compared to open field farming, because of the influence of the tree and grass components on surface cover.

Intercropping for increasing crop yield

Prasad and Srivastava (1991) and *Jagtap et al.* (1993) reported higher yields and returns under soybean-based intercropping systems than soybean alone. Dhing *et al.* (1991) found that legumes as inter-crops with maize, increased maize yield. Francis *et al*. (1993) studied pea intercropping at three different maize plant densities (6700, 9500 and 11,900 plants per acre) in South Carolina. The plantings were on raised beds, in the centre of each bed was a maize row with two rows of peas planted 18 inches either side of the maize row. Peas were established at a rate of 31,800 plants per acre in all intercrop plots. In the pure pea stand, each bed had two rows of peas spaced 24 inches apart. Intercrop yields and pure stand yields are shown in Table 1.4.

Table 1.4. Yields of maize and southern peas from intercrops (A: low maize density; B: middle maize density and C: high maize density)

Items	Maize (pounds/acre)	Peas (pounds/acre)	LER
Pure maize	5600	***	***
Pure peas	***	1200	***
Intercropping A	4200	800	1.24
Intercropping B	4600	800	1.32
Intercropping C	5000	500	1.26

(Source: Francis *et al*., (1993)).

From Table 1.4 it can be concluded that the maize intercropping improved overall crop productivity. Similar results were obtained in a study by Amador (1980) which compared mixed planting with individual crops grown separately near Tabasco, Mexico. Martin *et al*. (1987) conducted several maize-soybean intercrop seeding rates in Canada to determine their economic advantages as silage. Pure stands of maize and soybeans were grown for comparison at 24,000 maize seed per acre and 200,000 soybean seed per acre. Results showed that intercrops were more cost effective than pure stands over both years the study was conducted.

Intercropping for Disease Control

Intercropping also can decrease or prevent some pest outbreaks. Farmers in Yunnan Province changed planting from typical pure stand of a single rice variety to planting a mixture of two different rice varieties (Wolfe, 2000; Zhu *et al.*, 2000; Zhu *et al.*, 2003). The aim was to reduce the incidence of rice blast (the main rice disease) and the technique was so successful, many farmers abandoned using chemical fungicides.

In summary, intercropping has been an important practice in both developed and developing countries. It has biological, environmental and economic influences. Farmers have generally regarded intercropping as a technique that reduces risks in crop production, if one crop of an intercrop fails, the other may survive and compensate in yield to some extent, allowing the farmer an acceptable harvest. Generally, intercropping increased plant diversity, lowered pest populations and hampered pest movement. Some intercropping systems can improve soil fertility, such as intercropping legumes that fix nitrogen.

1.3.4b Crop rotation

Rotation is a common crop system, it is an alternation of different crops in the same field in some regular sequence. It differs from the haphazard change of crops from time to time. A deliberately chosen set of crops is grown in successive cycles over a period of years. Crop rotation reduces the potential for problems associated with continuous cropping, such as weeds, pests and diseases, as well as issues of fertility, nutrient leaching and soil quality and structure. Diversification through rotation also reduced reliance on one market and exposure to price fluctuations.

Practice in many regions has demonstrated that crop yields decline if the same crop is grown continuously in the same place. The common observation is that maize produces less yield when it follows maize, rather than another crop (Hesterman *et al.* 1986; Crookston and Kurle, 1989; Porter *et al.*, 1997; Crookston *et al.*, 1991). Maize following maize resulted in more barren stalks and fewer kennels per ear than maize following soybean in a dry year (Alice and Donald, 1999). The previous crop was a much more important determinant of no-till maize yield, than surface residue type. Use of mulch and crop rotations may almost eliminate the need for weed control (Calegari *et al.*, 1998). From this review on cultivation practices it may be concluded that contour planting, mulching with either natural or synthetic materials and intercropping techniques have been commonly used for arable crops on sloping land. Practices based on appropriate combinations of those techniques maybe particularly effective for increasing crop yield of reducing soil erosion.

1.4 Overview of maize and soybean crops

In this study, maize has been selected as the main crop for investigation as it is one of the major crops on sloping land in the experimental location. Increasing its productivity is a regional priority. Soybean has also been identified as an important crop in this region, especially, as part of an intercropping strategy.

1.4.1 Maize

General introduction

Maize (*Zea mays* L. ssp. *mays*) is cultivated world-wide. Man has cultivated and selectively bred maize for its useful characteristics for thousands of years; the extraordinary number of cultivars of modern maize is the result of human efforts to grow this crop in a variety of soil conditions, climates and topographic settings. The extreme adaptability of maize is reflected by the fact that yellow flint corn of the Caribbean thrives at sea level, whereas Puño maize is cultivated successfully at elevations of 3800 m. Chococeno maize of Columbia grows in wet, coastal area, while varieties of Hopi corn are planted in sand dunes (Nabhan, 1989). Domestication of maize began in southern Mexico ~5,000-6,000 years ago (Karanja, 1990), and today it is the third largest plant food harvested worldwide by volume (after wheat and rice), It is mainly grown in the USA, China and Brazil. It is a valuable food source for humans and animals (Wilkes, 1989). Annual production was 600 million tonnes in 1989 (FAO, 2000). Developing countries account for 64% of the world's maize area and 43% of global maize production (CIMMYT, 2000). The USA is by far the largest producer of maize, with an output of 270 million tonnes in 1986 and the planting area was 28 million ha, which occupied 21.3% of the whole world planting area. This is followed by China, with 19 million ha planting area which occupied 14.6% of the whole world planting area (Beijing Agriculture Technique Extent Station, 1987). Maize is a main food source in some countries, such as in Kenya where maize is the staple food for over 90% of the population and provides 42% of dietary energy intake (Karanja,1990). It occupies a much larger area than any other crop with >1 million ha of the crop being grown (Republic of Kenya, 1994). Uses for maize include food additives (sweeteners and starch), cornflakes, popcorn, sweet corn, rubber, animal feed, plastics, fuel and clothing.

Origin of Maize

The exact period of domestication and the ancestors from which maize arose are unclear. Archaeological records suggest that domestication of maize began at least 6000 years ago, occurring independently in regions of the south-western United States, Mexico and Central America (Mangelsdorf *et al.*, 1981). The origins of domesticated maize have been difficult to trace, as hybridization events in its evolution are thought to have involved a now extinct wild maize ancestor, of which little evidence is found (Eubanks, 1997). *Teosintes* (Z. *diploperennis* and Z. *may* ssp. *mexicana*) and *Tripsacum* species are often described as having roles in the domestication process of maize (Mangelsdorf *et al.*,1981; Galinat, 1988). An early hypothesis proposed that Z. *may* ssp. *Mexicana* was the product of a natural hybridization of *Tripsacum* and *Zea* (Mangelsdorf *et al.*, 1981). For modern races of maize, the possibility of inter-generic hybridization of either Z. *diploperennis* or *Tripsacum* with an extinct wild maize has also been proposed as the ancestral origin of Z. *mays* (Purseglove, 1972; Radu *et al*., 1997).

Biology of Zea mays

Maize (*Zea may L*) is a C4 plant and is a member of the Gramineae grass family (Hesketh and Musgrave, 1962). It is unisexual (monoecious) flower plant (produces separate male and female flowers on the same individual plant), and generally male flowers are called ‘tassels’ which develop at the stem tip and release wind-borne pollen. Female flowers are on the middle or side branches of the stem, which form ears, if successfully fertilised some ears develop into ‘cobs.’ The main stem is made up of clearly defined nodes and internodes. Internodes are wide at the base and gradually taper to the terminal inflorescence at the top of the plant. Leaf blades are found in an alternating pattern along the stem and sheath, a basal part that wraps tightly around the stem (Poethig, 1982).

The reproductive phase begins when one or two auxiliary buds, present in the leaf axils, develop and form the pistillate inflorescence or female flower (Purseglove, 1972). The auxiliary bud starts the transformation to form a long ‘cob’, on which the flowers develop each flower, a style begins to elongate towards the tip of the cob in preparation for fertilization. These styles form long threads, known as silks. The base of the silk is unique, as it elongates continuously until fertilization occurs (Purseglove, 1972). The seed (grain) is composed of an ‘embryo’ from which a new plant will develop and ‘endosperm’(the nutrient source for the germinating seedling), which is composed mainly of starch, a storage carbohydrate (Cobley, 1976). Figure 1.2 shows the general maize embryo structure.

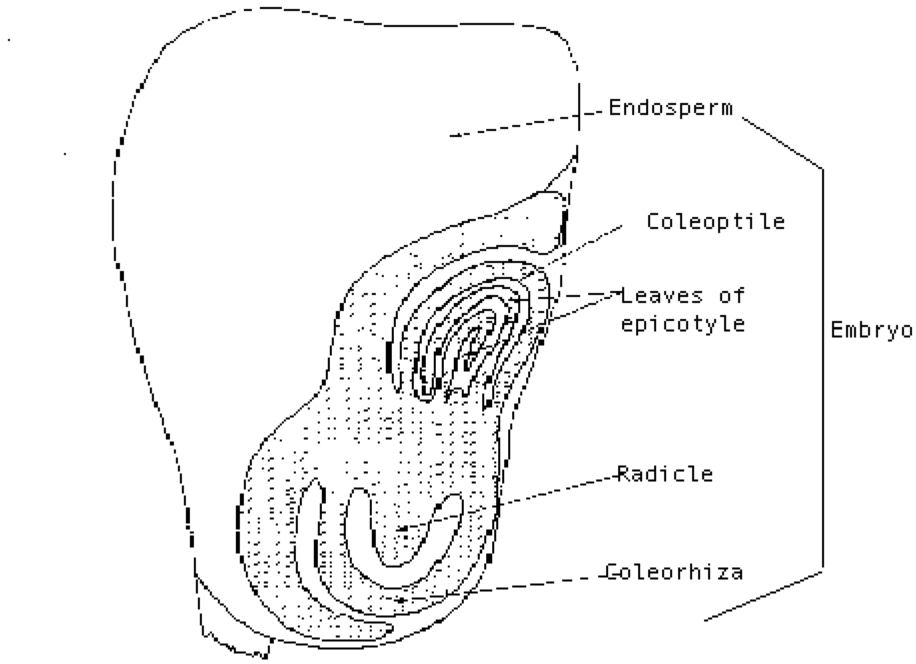


Figure 1.2. The general maize seed longitudinal structure (Source: Cobley, 1976).

After maturation and harvesting (or dispersal) the grain will subsequently germinate, determined by the protrusion of the radicle. The radicle grows underground to develop into the seminal roots, which spread widely through the soil and absorb water and minerals, which are conducted to the stems and leaves. Lateral roots begin to appear which, with their branches, greatly increase the absorbing and anchoring power of the root. The remaining portion of the root system arises from the nodes or joints of the stem in the soil (Purseglove, 1972). At later maize growth stage, there are roots originating from nodes above the soil, called brace roots (Fischer and Palmer, 1984). The main purpose of brace roots is to support the stem. Figure 1.2 shows the general maize embryo structure.

Cultivation of Maize

Maize growth is influenced by climate, soil fertility, soil temperature and moisture, soil structure and added fertilizers. The suitable environmental weather conditions for maize are high temperature and moisture and long hours of sunshine. Unfavourable conditions, such as shallow soil, dry climate, low temperature and moisture in early growth stages may slow down the rate of canopy development, limiting canopy size, light interception and dry matter accumulation and thus low yields (Iowa State University, 1993).

Though maize is one of the most widely adapted crops grown, its susceptibility to frost makes the number of growing days the most important limiting factor in its production. Modern hybrid maize requires a growing season of ~120 frost-free days and if grown under dry conditions may require longer to mature (Minnis, 1985; Muenchrath and Salvador, 1995). Maize needs high intensity radiation during its whole life, if the light is shaded after its pollination, the yields will reduce greatly (Shun, 1997).

Maize requires a minimum soil temperature of 12°C for germination. From emergence onwards, maize grows optimally at an average day temperature of 24°C and night temperature of 14-16°C. Below 12°C maize is not biologically active (Purseglove, 1972). Generally, seed germination periods depend on temperature, if temperature is 10-13°C, the germination needed is 18-20 days and if temperature is 16-18°C, it needs 8-10 days, if temperature is >21°C, it just needs 5-6 days. But if temperature is >40°C, seed germination is stopped. After seeding, maize grows very fast between 25-35°C and with temperature increasing by 1°C, the staminate flower growing is advanced by 5-7 days (Shun, 1997).

Adequate annual rainfall (600-1000 mm) is required for short-season maize production. Additional rainfall is required for high intensity production and where longer growing seasons exist. Purseglove (1972) and Muenchrath and Salvador (1995) found that modern hybrid maize requires ~400-600 mm of water during the growing season. Generally, 150 mm of growing season rainfall is considered the lower limit for maize production without irrigation. Inadequate rainfall during the early season can cause poor establishment and in extreme situations, crop failure. Water deficiency when the maize is at the tasseling or silking stage may decrease yields by 50-75% (Classen and Shaw, 1970; Minnis, 1985; Muenchrath and Salvador, 1995). Shun (1997) estimated that ~3000 m^3 water is required per hectare.

Soil is very important to maize growth, it not only gives firm anchorage for the plants, but also supplies the nutrients. In the semi-arid Tehuaca'n valley, Mexico, Joseph *et al.* (2001) estimated that the extreme loss of soils near Metzontla caused the virtual collapse of significant maize production on hillslopes. With continued tillage and planting and sowing where soil thickness is <10 cm. The maximum plant heights of in such shallow soil was only 50 cm and plant failed to flower. In fields with soils between 10-30 cm deep, only 25% of maize plants produced grain and estimated maize grain yields were 60-99 kg ha^{-1}.

In order to maximize maize yields, besides the suitable environmental conditions, several cultural practices are usually employed, such as the use of inputs like nitrogen fertilizer, crop rotation and weed control. Maize, especially hybrid seed, demands high levels of nitrogen to maximize vegetative growth and yields (Stoskopf, 1985). The rotation of maize with other crops is essential to reduce the presence of diseases and pests that remain in the soil from remaining maize stalks and leaves (Purseglove, 1972). Weed control is also important.

Maize in China and Yunnan

Maize was introduced to China at the beginning of 16th Century and during the Daoguang Emperor years (1850) it had developed to be one of the "Liu Gu" (six main crops: rice, wheat, millet, sorghum, soybean and maize) (Dong, 2001). Compared with rice, it is easy to cultivate and adapts well to different environments, especially on sloping mountainous areas. During the years of Emperor Daoguang, the high population (400,000) and less tillage land (0.11 ha per capita) forced people to cultivate much more steep and marginal areas to grow maize (Li, 1957). It is also from this time that the exploitation of virgin land for maize cultivation destroyed large areas of forest and brought more problems (such as soil erosion and land slides) for future generations.

Maize developed very fast from its introduction. Wu Hui (1985) concluded that in 1812 the total maize planting area was 0.4734 million ha and occupied 6% of the total tillage area, the mean yield was 1.35 t ha^{-1} and the total maize production was 18.2 M t. But in 1987, the maize planting in China extended to 1900 million ha, the total grain product was 700,000 million tonnes and the mean yield was 3.748 t ha^{-1}. From 1949-1980, the rate was double that of wheat (Table 1.5)

Table 1.5. Changes in crop production in China from 1949 and 1980 (Beijing agriculture technique extent station, 1987)

Item	1949 year				1980 year			
	Planting area		Total yield		Planting area		Total yield	
	ha	%	kg	%	ha	%	kg	%
Maize	1106.7×10^4	10.1	117.5×10^9	10.4	2035.3×10^4	17.3	626×10^9	19.5
Rice	2570.9×10^4	23.4	486.5×10^9	43.0	3387.9×10^4	28.9	1399×10^9	43.6
Wheat	2151.3×10^4	19.6	138×10^9	12.2	2922.8×10^4	24.9	552×10^9	17.2
Total	10995.9×10^4	100	1132×10^9	100	11723.4×10^4	100	3205×10^9	100

The maize planting distribution in China is in six main areas: the northern spring sowing zone, the Huang Huai hai summer sowing zone, the south-west mountain zone, the southern planting zone, the northern-west planting zone and the Qingzang Plateau planting zone.

In Yunnan Province, maize is the second crop after rice. Following the whole country's trend, maize developed fast in Yunnan Province: in 1952, the planting area was 83.83×10^4 ha. In 1989 the planting area was 97.91×10^4 ha and occupied 34.7% of the total tillage area. Total yield was 292.8×10^4 T which constituted 29.3% of total crop production (Dong, 1991). In 1996, the planting area extended to 1.12 million hectares (Yunnan Provincial Government, 1996). Table 1.6 summarizes the maize planting area and total production from 1987-2001 in Yunnan. The yield greater increase was contributed by high fertilizer input, insecticide application, hybrid breeding and advanced agricultural technology (Zhou, 2002).

Table 1.6. Maize planting area and total production in Yunnan Province

Year	Planting Area (ha)	Yield (kg/ha)	Total Production (kg)
1987	952900.0	2621.47	24.98×10^8
1990	989866.7	2845.84	28.17×10^8
1995	988466.7	3457.88	34.18×10^8
2000	1155067.0	3861.25	44.60×10^8
2001	1137200.0	3951.81	44.94×10^8

(Source: Zhou, 2002).

Maize grows on a wide altitudinal range in Yunnan, from Honghe River valley to high mountain areas at 3200 m (Nixi village, Zhongdian County). Most is grown in the six prefectures of Qujin, Zhaotong, Wenshan, Honghe, Linchang and Simao, in which it occupies 67.7% of total planting area and provides 69.5% of total yields (Dong, 1991).

Although in Yunnan Province maize is mainly used for fodder, for most mountain people maize is still a staple food (Dong, 1991). Some 80% of people who inhabit the mountains are minorities, they live below the poverty line and cannot satisfy their basic living needs (Yunnan, 2000). So improving maize yield is crucial for these areas. However, local natural conditions, the traditional planting methods and the agricultural skills make maize yields variable. Generally the mean yields fluctuated ~4.0 t ha^{-1}, this is less than half of the unit yield of the USA (8.1 t ha^{-1}) and also less than the average of all China's yield (4.91 t ha^{-1}) (USDA, 1998). It is very important to achieve high productivity on these sloping lands and establish a more sustainable crop system. This is the main objective of local government and research work.

In summary, maize is a very important global crop. Though its wide environmental adaptability makes it easy to cultivate, to achieve high yields, it also responds best to moderately high temperature, high moisture, strong radiation, good soil fertility and good management.

1.5.2 Soybean

Soybean was first domesticated in eastern north China in the 11th century BC (Jules and James, 1990). Soybean was later introduced into Korea from North China and into Japan and other Asian countries and then progressively throughout the world. It is a very important protein source in the diets of many Asian nations and is an extremely valuable food and industrial product throughout Asia. In addition to extracting oil from soybean for food and industrial purposes, soybean has also been used for soy sauce, soymilk, soy curd, soy paste and bean sprouts. The residue after oil extraction has been used for fertilizer and animal feed. In the United States the principal early use of soybean was as a forage crop. The crop was frequently harvested or ploughed under as a green manure crop to improve soil structure. In 1999, the global production was 155.1 million tonnes, with the major producers being the United States, Brazil, Argentina, China and India (USDA, 2000).

Soybean (*Glycine max*) belongs to the Fabaceae family. The seed consists of two cotyledons, which contain nutrients and energy that nourish the seedling. Under normal field conditions, seedling emergence usually occurs 5-9 days following planting. The cotyledons provide energy for plant growth for about two weeks and they are the first photosynthetic organs of soybean seedlings. Soybean plant has two unifoliolate leaves, which consist of a petiole and a single leaflet and are attached opposite to each other at the second node. From the third node a single leaf with three leaflets at each node alternately is attached opposite to each other at the stem (trifoliolate leaves). Most photosynthesis takes place in the trifoliolate leaves. Soybean has two general types of stem termination, determinate and indeterminate. The indeterminate type continues to produce new stem and leaf growth for several weeks after it begins to flower. The terminal growing point of plants with determinate stems develops a flower cluster and ceases to produce new vegetative growth soon after flowering begins. Flowering usually begins in the lower part of the plant, commonly at the fourth node, and then progresses towards the bottom and top. The flowers are normally self-pollinated and 25% of the flowers develop into mature pods containing seeds. The radicle normally develops into the primary root of the soybean plant (main taproot) and lateral branch roots develop from the taproot. Root hairs develop near the tip of each growing root. For soybean root, nitrogen fixation is essential, as it is a host of nitrogen fixing bacteria (Rhizobium).

Climatic requirements for soybean are similar to maize, but it can withstand short periods of drought and light frosts. Soybean is a short day plant and is sensitive to photoperiods, most varieties require 10 hours of darkness in order to flower. It adapts to lower fertility soils than maize and it can grow on soils that are too acid for alfalfa and red clover. In Yunnan, soybean is widely planted because of the suitability of the climate, weather and general soil conditions.

1.5 General overview of Yunnan

The main experimental site is located in Yunnan Province, and was selected because of previous collaboration between the University of Wolverhampton and Yunnan Agricultural University, the importance of maize production and the seriousness of soil erosion problems associated with arable cultivation on sloping land.

1.5.1 Location of Yunnan

Yunnan is located in South West China, between 97°31'39"-106°11'47" East longitude and 21°8'32"-29°15'8" latitude. It borders Guizhou Province and Guangxi Zhang Ethnic Minority Autonomous Region to the east, Chongqing and Sichuan to the north and Tibet Autonomous Region to the Northwest. To its west is Myanmar and to the south are Laos and Vietnam (Figure 1.3). The border stretches for 4,060 kilometres. The land area is 394,100 km^2, the eighth largest province in China. By comparison with other countries, it is slightly larger than Japan and Italy and about the same size as France. The Province has a total population of 41.589 million (total registered population 1997), with 16 prefectures, autonomous prefectures and cities. Most of its population lives in the eastern river basins and the western mountainous and semi-mountainous areas are sparsely populated. Population density is high in the middle and low in both the southern and northern areas (Yunnan Year Report 2000).

Yunnnan is a highland province with a terraced topographical feature stretching from the north-west to the south-east, resulting in a diversity of elevations and climates. About 94% of the Province is mountainous and the average altitude is 1,980 m. The difference between the highest and the lowest points is 6,663 m. The Province descends like a ladder from north to south. The highest point in the north is Kagebo Peak in Deqin County on the Deqin Plateau, which is 6,740 m high. The lowest is in the Honghe River Valley in Hekou County, with an elevation of 76.4 m. The terrain descends on average 6 m every kilometre towards the south. As expected, this creates sharp differences in temperature throughout the Province.

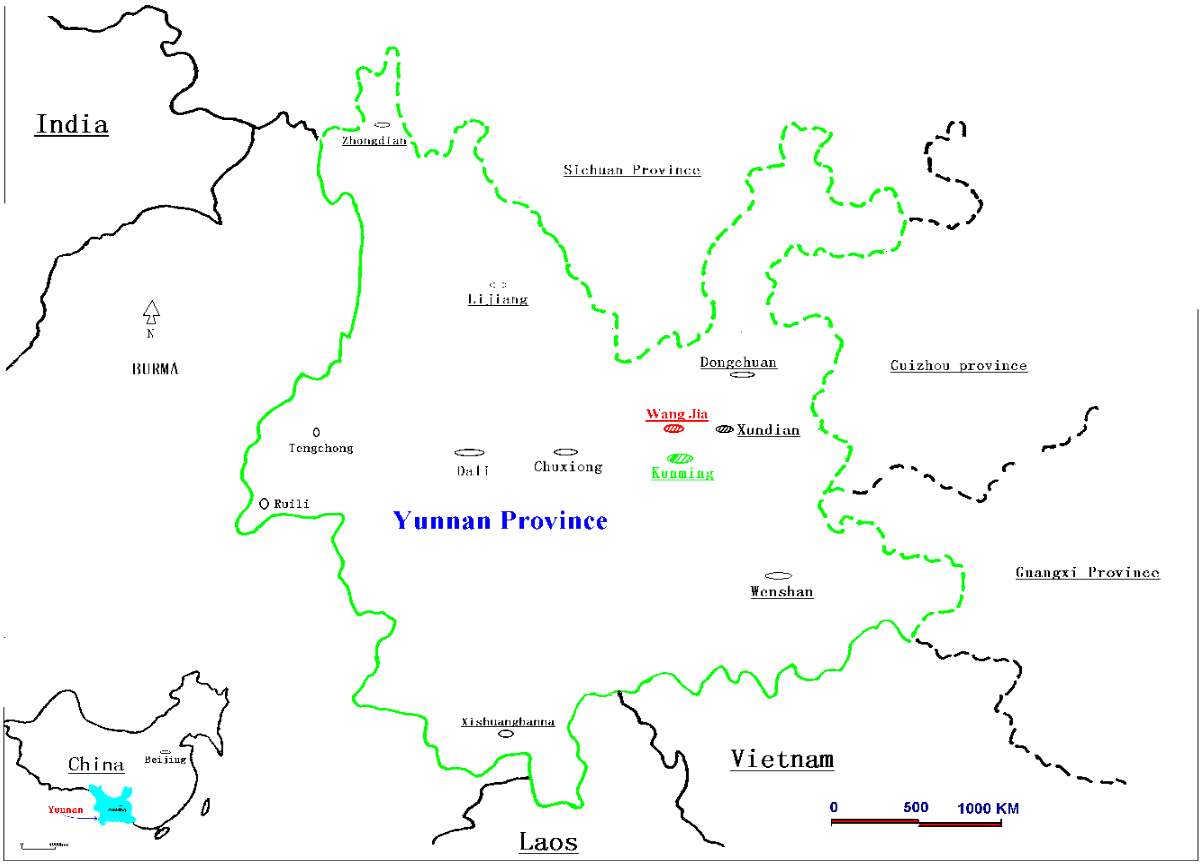


Figure 1.3. Geographic Location of Yunnan Province, showing the bordering Provinces and countries.

1.5.2 The Climate of Yunnan

Yunnan has diverse climatic conditions. It has a vertical climate complex from tropical and subtropical. From north to south, the Province spans three main climatic zones: temperate, subtropical and tropical. Conspicuous changes in climate occur, with two clear-cut seasons, dry and humid. The rainy season is from May to October. Average temperature is 8-17°C in January and 11-29°C in July. Annual average rainfall is 600-2,300 mm. Precipitation is low in the north-west and high in the south-east. Some of 60% of rain falls from June-August (Yunnan Year Report, 2000).

The complex geographical conditions and varied climate give Yunnan a very varied vegetation and land surface, glaciers and snow-capped mountains with alpine vegetation at the highest latitude, and sub-tropical basins, hot valleys and lush tropical vegetation at the lowest. Local residents describe the Province as "having four seasons on one mountain, and a different weather 10 km apart." Topographical and climatic differences, along with longer frost-free periods and more sunshine, provide Yunnan with perfect conditions for developing a widely diverse agriculture.

The weather is very dry in winter when the land is under the control of continental monsoons, and the summer is wet as humid air advects from the Indian Ocean. One can experience seven different types of climate in the Province, namely those of the northern tropical zone, the southern Asia tropical zone, the central Asia tropical zone, the northern Asia tropical zone, the southern temperate zone, the central temperate zone and the alpine zone (Fig 1. 4).

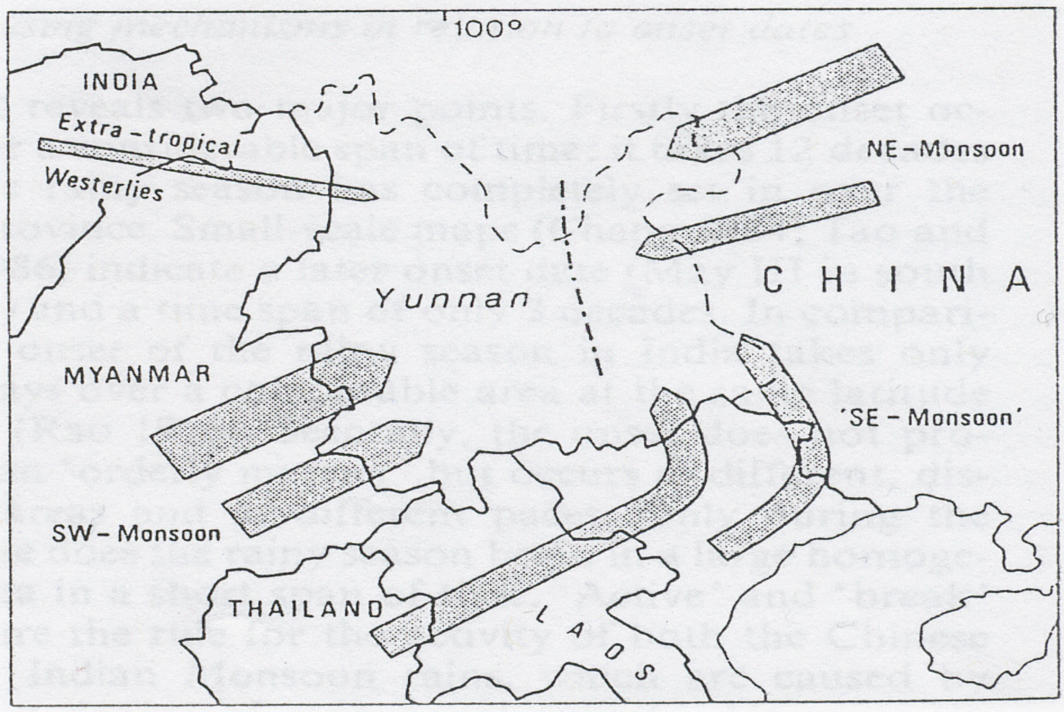


Figure 1.4. Branches of atmospheric circulation affecting precipitation in Yunnan Province (Source: (Thomas, 1993).

1.5.3 Yunnan crop production

Despite the variation, overall, Yunnan has a mild climate with usually fine weather, and although the growing period is long, there is little arable land. However, cultivated land constitutes only a small part of the total land, owing to steep mountains, so agriculture is restricted to the few upland plains, open valleys and terraced hillsides. Rice is the main crop;

maize, wheat, sweet potatoes, soybeans (as a food crop), tea, sugarcane, tobacco and cotton are also grown. Total grain output in this Province keeps increasing. However, the per capita share remains still lower than the national average. The grain output was 12.72 million tonnes in 1997 (Yunnan Annual Report, 2000).

1.6 Description of the research catchment

Collaboration was organized with Kedu Township, which led to the identification of Kelang as a suitable village and the catchment of Wang Jia was selected for research. It was selected because the catchment connects to one village (Kelang) and all the farmland is managed by the farmers of this village. It has a stream running down the catchment, facilitating hydrological studies on sediment loads. At the outset of the Project, maize and tobacco were the most important summer crops, with maize being grown on the steeper slopes. The main winter crops were wheat and pea.

Wang Jia Catchment is located ~60 km north-east of Kunming. It is a SSW-NNE elongated catchment with a width ranging from 200-345 m. The elevation extends from 1860-2380 m, total elevation difference (relative relief) is 520 m and total length is 1930 m. The mean general slope is 15° (Figures 1.5 and 1.6). The village of Kelang is situated at the base of the catchment (Plate 1.3), which belongs to Kedu Township. In 2000, there were 876 households and the total population was 3610 (1778 male and 1832 female). There were 1668 total labourers engaged in gainful employment and 51.9% involved in crop production in 2000.

Total land for cultivation is 162 hectares where the dry land is 99.2 hectares and 79.2% of land is sloping. The villagers cultivate both Wang jia sloping land and neighbouring flat land. Total crop grain yield was 879 tonnes in 2000, equivalent to a mean crop per capita of 243.5 kg.year^{-1}. Tables 1.7 and 1.8 show the general situation of Kelang village from 1990-2000. (Source: Kedu Township Yearbook, 2001).

Plate 1.3. General view of Wang Jia Catchment and Kelang village during early summer times (Photo was taken in May 2001)

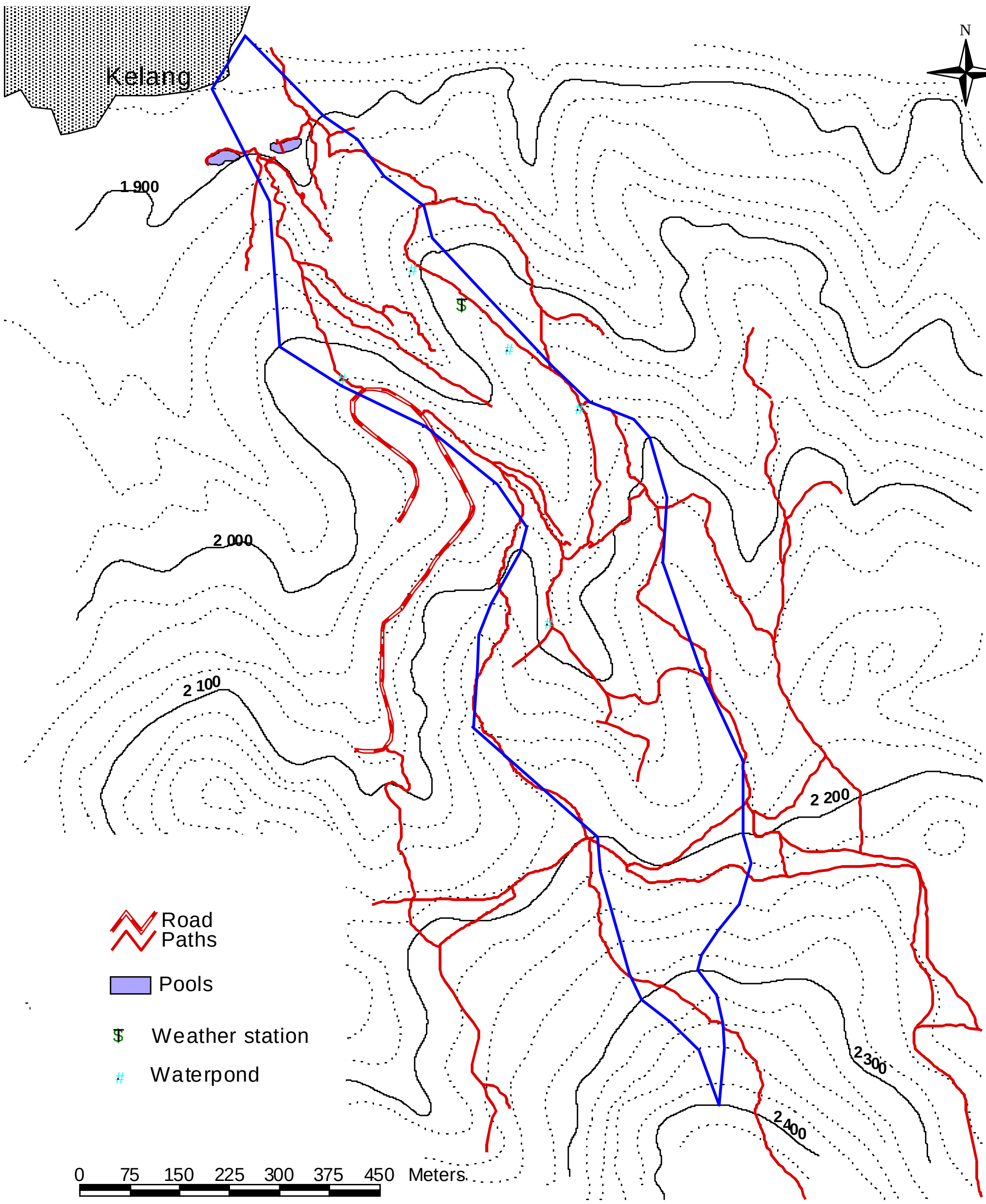


Figure 1.5. Map of Wang Jia Catchment showing the catchment boundary, contours and main features (Source: Gembloux Agricultural University, Belgium).

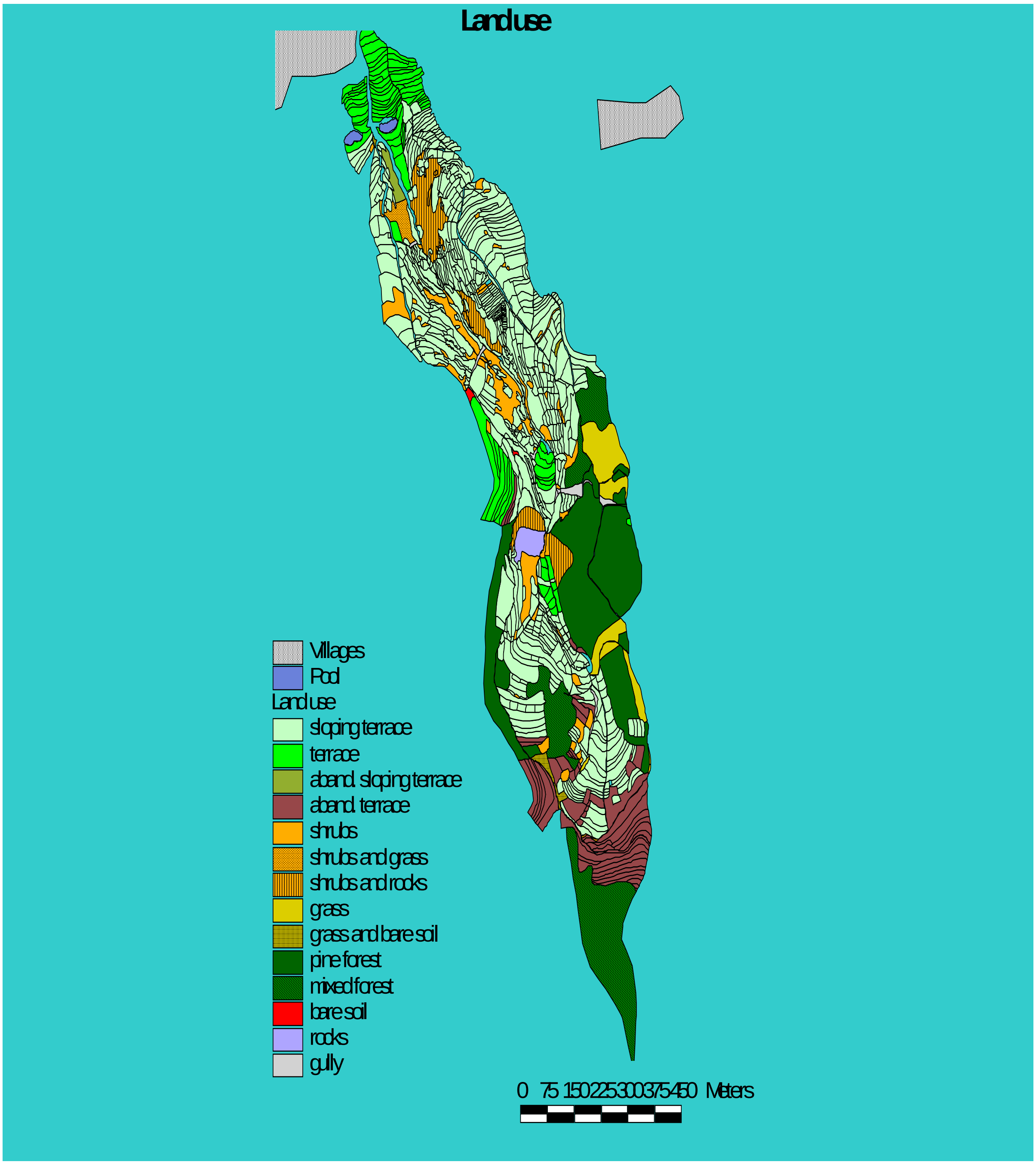


Figure 1.6. Wang Jia Catchment land use with map features superimposed. (Source: Gembloux Agricultural University, Belgium).

Table 1.7. Kelang village general situation from 1990-2000 (Source: Kedu Township Yearbook, 2001)

Year	No of Households	Population	Male	Female	Labour	Male labour	Female Labour	Labour engaged in crops	Arable Land (ha)	Dry land (ha)	Gross cereal yield (Mg)
1990	714	3159	1570	1589	853	441	412	625	164.6	99.2	865
1991	840	3227	1611	1616	1400	715	685	1153	162	99.2	882
1992	759	3288	1623	1665	1394	713	681	1165	162	99.2	656
1993	762	3317	1632	1685	1248	652	596	1015	162	99.2	884
1994	771	3366	1655	1711	1251	665	586	1023	162	99.2	700
1995	777	3417	1690	1727	1264	672	592	1012	162	99.2	824
1996	805	3437	1710	1737	1302	678	624	1008	162	99.2	886.8
1997	809	3447	1696	1751	1309	682	627	916	162	99.2	859.9
1998	839	3510	1733	1777	1338	689	649	895	162	99.2	853
1999	860	3560	1757	1803	1620	718	650	887	162	99.2	944
2000	876	3610	1778	1832	1668	745	657	866	162	99.2	879

Table 1.8 shows that for 2000 in Kelang the main crops were rice, maize and potato during the summer season. In winter, crops are mainly wheat, with lesser amounts of barley and peas. Tobacco was the most important cash crop.

This Ph.D research work is directly relevant to improving productivity and sustainable agricultural development in the highlands of Yunnan. The results from the Project will contribute to the SHASEA programme “Improving the productivity and sustainability of crop systems on fragile slopes in the highlands of south China and Thailand”. This project aims to find environmentally–friendly ways to improve crop productivity and sustainability and alleviate poverty in the uplands. In the longer term, the programme is aiming to recommend novel agricultural techniques suitable for more sustainable agriculture and productivity improvement in the highlands of south China. It will also provide a socio-economic evaluation of the effects of these cropping strategies.

Table 1.8. Crop productivity in Kelang village from 1990-2000

Year	Summer crops								Winter crops				Cash crops		
	(1) Rice		(2) Maize		(3) Potato		(4) Other crops		Wheat		Barley and Pea		Tobacco		Others
	Planting area (ha)	Gross yield (t)	Planting area (ha)	Gross yield (t)	Planting area (ha)	Gross yield (t)	Planting area (ha)	Gross yield (t)	Planting area (ha)	Gross yield (t)	Planting area (ha)	Gross yield (t)	Planting area (ha)	Gross yield (t)	Planting area (ha)
1990	59.33	341.00	34.67	182.00	10.00	50.00	13.33	50.00	70.00	126.00	26.67	24.00	1.60	94.00	0.00
1991	58.67	363.00	26.33	152.00	10.00	32.00	13.33	60.00	70.00	133.00	24.00	29.00	1.93	138.00	0.00
1992	58.07	339.00	14.47	5.00	0.80	3.00	30.67	32.00	70.00	139.00	24.00	30.00	2.00	115.90	0.00
1993	42.53	376.00	14.47	169.00	2.00	12.00	2.67	52.00	68.00	133.00	21.33	38.00	2.53	260.00	0.00
1994	43.33	291.00	14.47	310.00	0.80	4.00	2.67	16.00	68.00	189.00	21.33	45.00	3.00	228.00	0.00
1995	29.33	290.00	14.47	152.00	0.80	6.00	13.33	63.00	61.33	147.00	21.33	44.00	2.93	285.00	0.00
1996	56.00	409.00	12.67	79.30	1.00	28.00	3.33	27.50	61.33	162.00	26.00	74.00	4.93	372.60	0.00
1997	56.00	379.00	10.00	58.00	0.00	0.00	15.00	49.00	65.07	167.00	23.87	76.86	5.12	526.20	6.67
1998	59.00	363.00	33.33	150.00	2.67	15.00	16.00	31.00	61.73	126.00	29.87	72.00	4.80	168.20	2.00
1999	59.00	385.00	33.33	170.00	2.00	16.00	16.00	31.00	61.73	135.00	29.87	78.00	5.20	159.00	8.00
2000	56.67	370.00	32.00	170.00	3.33	19.00	10.33	27.00	55.73	149.00	34.47	49.00	3.27	164.00	2.67

(Source: Kedu Township Yearbook, 2001).

1.7 Previous work

This study is a progression of a long-term research programme aim at improving crop productivity and conserving soil, water and nutrients on sloping land in Yunnan. The previous work and findings are briefly outlined. In phase 1 involved plot studies at Yunnan Agricultural University focused on the effectiveness of measures designed to reduce soil erosion. Phase two involved preliminary actual field plot studies at Wang Jia Catchment.

Phase 1: Runoff /erosion plot studies in Yunnan Agricultural University

From 1988-1990, research on different cultivation and tillage measures on soil erosion and crop productivity was conducted on the Yunnan Agricultural University Campus, led by Professor Liu Liguang and Professor Wu Bozhi (Liu *et al.*, 1991). In this experiment, ploughing depth (20 cm and 7 cm), cultivation direction (down slope cultivation and contour cultivation) and planting (mono-culture maize and intercropping with potato) were investigated in small plots at one slope angle (10°). There was no repeat for the treatments and the result were the mean of three years of data. Results showed that contour cultivation reduced runoff and soil loss, soil organic matter and soil nutrients compared with downslope cultivation. Intercropping was also effective compared with monoculture and shallow ploughing compared with deep ploughing. Contour cultivation increased yield by 17.6% compared with downslope cultivation; intercropping increased crop yields by 23.0% compared with mono-culture and shallow ploughing increased yields by 10.0% compared with deep ploughing. The authors recommended contour cultivation, shallow tillage and intercropping on sloping land.

Commencing in 1990, full field surveys were carried out in diverse environments within Yunnan Province by scientists from the University of Wolverhampton and in co-operation with the local scientists from Yunnan Agricultural University. This survey led to practical suggestions for integrated assessments of agro-environmental problems (Fullen, 1998; Barton, 2000) and built an valuable foundation for future research. In 1993, a formal collaborative project was established between the University of Wolverhampton and Yunnan Agricultural University, to evaluate appropriate agronomic soil conservation measures on sloping red soils in Yunnan

Province. Thirty runoff/erosion plots were established at the experimental site of Yunnan Agricultural University. In 1993 and 1994, the plots were run by Yunnan Agricultural University, to evaluate the effects of five different cropping practices on soil conservation and crop productivity. The cropping practices used were conventional tillage, no-tillage, straw mulch, polythene mulch and intercropping with soybean. In 1995 and 1996, the same cropping techniques were used in an unreplicated study on the three slopes (3, 10 and 27°) by A. Barton for a Ph.D. thesis (Barton, 2000). Barton concluded that straw mulch was the most effective soil conservation method, even on the steep slope. Contour cultivation also effectively reduced soil erosion compared with downslope cultivation. Barton also found that polythene mulch encouraged faster growth and higher yields than the other treatments, but enhanced runoff loss. Convention tillage had the poorest growth and the other treatments were in the middle between polythene and conventional tillage. In 1998 and 1999, these 30 plots were operated by E. Milne for a Ph.D. thesis (Milne, 2001) to examine in more detail using replicated plots, contour cultivation and contour cultivation plus straw mulch and their effects on maize productivity and soil nutrient status compared to traditional downslope. The set of plots at each general slope angle included one bare plot, with no replicate. Milne concluded that on the gentle slope (3°) and in a year with greater than average rainfall, both contour cultivation and contour cultivation plus straw mulch did not significantly reduce runoff, but both methods reduced soil loss. When slope increased, contour cultivation significantly reduced runoff and soil loss and contour cultivation plus straw mulch offered a further significant reduction. But on a steep slope (27°), contour cultivation alone did not prevent runoff or soil loss. Contour cultivation plus straw mulch reduced both runoff and soil loss by 100%. The further benefit for contour cultivation plus straw mulch was that it significantly increased soil moisture and soil water availability, which led to positives effect on maize growth and yield in conditions of limited water availability. Straw mulch also had beneficial effects on soil available N and K. Studies on the evaluation of other cropping practices in Yunnan Agricultural University erosion plots are on-going with Mr. An Tongxing and he completed his M.Sc. thesis in 2002.

Phase 2: Development of Wang Jia study

Further progress towards general recommendations required evaluation of the applicability and effectiveness of crop techniques developed from plot studies to actual field conditions. In 1998 and 1999, in the middle of Wang Jia Catchment, 15 plots were established to evaluate the effects of five different cropping practices on soil physico-chemical properties and crop productivity. The cropping practices used were traditional downslope tillage, contour tillage, minimum-tillage, straw mulch and polythene mulch. This research was conducted by Huang Bi Zhi for a Ph.D. thesis (Huang, 2001). Huang found that contour planting significantly increased crop yields compared with downslope cultivation. Minimum tillage was beneficial for nutrient retention and maintains high soil moisture when combined with straw mulch. Straw mulch combined with contour cultivation maintained higher soil moisture levels during the dry season and can then lead to higher grain yields compared with non-mulched downslope cultivation. Polythene mulch greatly promoted crop growth and led to increased grain yields. The reason appeared to be associated with high soil temperatures under the polythene mulch. This study excluded contour cultivation plus polythene and straw mulch, and intercropping techniques. Measurements of soil moisture and temperature were limited to intermittent sampling only.

In summary, previous work both of runoff plots at Yunnan Agricultural University and in Wang Jia have shown that contour cultivation can reduce runoff and soil loss on relatively gentle sloping land, but has less effect on steeper slopes. Intercropping improved crop yield on the Yunnan Agricultural University Farm. Straw mulch can significantly reduce runoff and soil losses, even on very steep slopes and maintain higher soil moisture contents during the dry season, leading to a higher grain yield. Crop growth and grain yield was highest on polythene mulch. However, polythene mulch alone had a potential danger to enhance runoff. The hypothesis was proposed that integrated contour cultivation, plus polythene and straw mulch, may benefit crop productivity and simultaneously conserve soil, water and nutrients. Therefore, an experiment using this cropping integrate technique and other conservation methods was established.

1.8 Aims and objectives

The aims of this research are to select, from several of practices previously evaluated in erosion plots, a number of cultivation practices with the potential for improving crop productivity and/or soil conservation and to evaluate them under field conditions on sloping land in a catchment managed by local farmers, using traditional methods where possible.

These aims will be addressed in a series of experimental objectives:

1. To investigate the effects of the treatments on maize productivity and soil properties.

These were (1) traditional down-slope cultivation and planting, (2) traditional cultivation and contour planting, (3) contour planting with polythene mulch, (4) contour planting with polythene and straw mulch, (5) contour planting polythene and intercropping with soybeans.

2: To devise a field experiment which evaluated these practices under conditions as close to farmer-managed conditions as possible, over three seasons.

3: To qualify the effects of these selected cropping practices on crop growth and crop yield components.

4: To determine the effects of these selected practices on a range of soil properties identified for their role in improving crop growth.

5: To analyse these effects in order to explain how any observed improvements in crop productivity may be achieved and also how these may relate to changes in soil conservation.

6: To carry out a simple cost-benefit analysis of the cultivation practices and the resulting yields in order to determine the potential economic benefits of those practices which are effective on the basis of technical/scientific considerations.

7: On the basis of the research, to propose cultivation practice(s) for adoption/ adaptation by local farmers in the catchment to achieve the long-term goal of increasing or maintaining maize productivity on sloping land in highland areas of Yunnan Province in a more sustainable way.

The Project will contribute to the development of a catchment management plan that embraced several strategies and practices aimed at improving the productivity of arable crops in more sustainable ways. The plan will include the diversification of the cropping system, so that appropriate perennial crops are established on the most fragile slopes, leading to the development of a model catchment for further maintaining and training demonstration purposes. If these practices demonstrate improved returns over the longer term, their wider adoption will make a contribution to the improvement of food security, alleviation of poverty and the development of more sustainable agricultural systems.

Chapter 2 Materials and Methods

Details of experimental design, materials and methods are given in this Chapter.

2.1 Experimental Site and Design

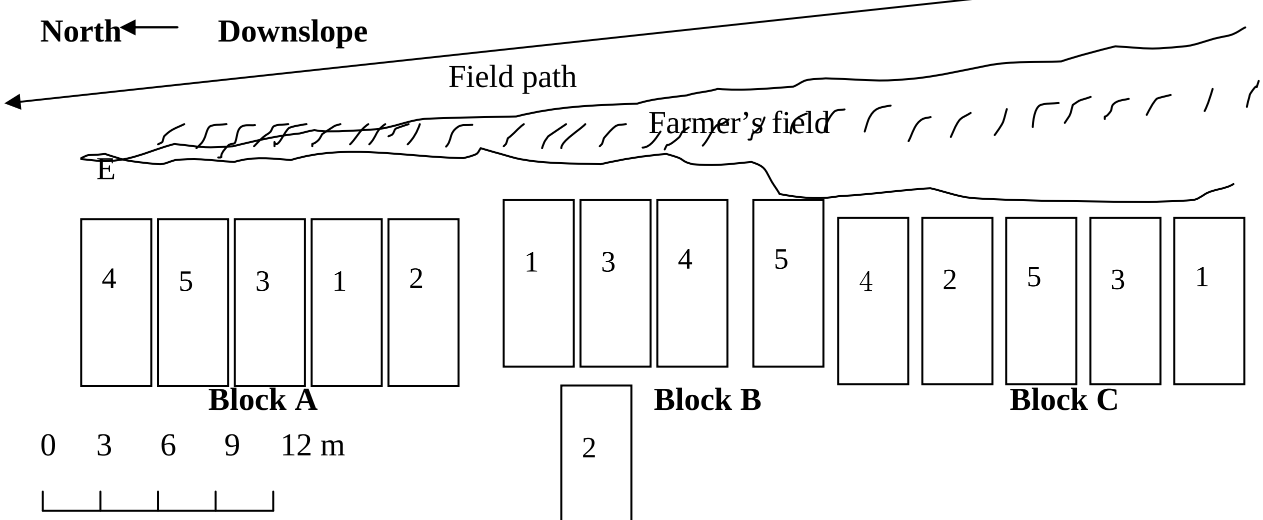
The study was conducted at Kelang village, Xingdian County, Yunnan Province, China. The experimental site is located at 25°28`N, 102°53`E in the middle of Wang Jia mountain range. This catchment was selected because it contains steep slopes, which are intensely cultivated and present evidence of serious soil erosion. Farmers from one village (Kelang) also farm the catchment. This allows the socio-economic impacts of these cultivation practices to be assessed. The treatments were chosen to encompass a wide range of agronomic conditions found within Yunnan and to evaluate their effects on crop performance. Traditional up-and-down slope planting is currently the most common cultivation practice for highland farmers. Some farmers adopt contour planting cultivation, but the proportion is small. Polythene mulch is mainly used for vegetable, flower and tobacco crops. For maize, few farmers use plastic film, especially on hilly lands. Straw mulch is rarely used on cultivated land, so the INCOPLAST (incorporation of contour cultivation with polythene and straw mulch) is a novel cultivation method. Intercropping plus polythene mulch was also tested in this experiment.

An area with slope of ~8-14° and large enough to accommodate the plots was identified on the east-facing slope of the catchment. Fifteen plots were marked out, each 3×10 m; 30 m^2 in area and in a randomized block design. The previous winter crop was wheat. The following treatments were applied:

1. **D:** Traditional cultivation and maize with downslope planting, no mulch.
2. **C:** Traditional cultivation and maize with contour planting, no mulch.
3. **C+P:** Traditional cultivation and maize growth by contour planting, with polythene mulch.
4. **C+P+S:** Traditional cultivation and maize growth by contour planting, with wheat straw and polythene mulch (INCOPLAST technique).
5. **C+P+IS:** Traditional cultivation and maize growth by contour planting, wide and narrow row spacing, with polythene mulch and intercropping with soybean in wide row spacing. Treatments were replicated three times in a randomized block (Plate 2.1, Figure 2.1).

Plate 2.1. The experimental site on the east of Wang Jia Catchment (25°28`N, 102°53`E)

Figure 2.1. Plan of experimental site showing arrangement of plots and allocation of treatments in blocks



1-5: different treatments, see page 47.

2.2 Agronomy:

During all three summer seasons (1999, 2000 and 2001), all plots were planted with maize (*Zea mays L*. CV. Dian feng 4, supplied by Yunnan Agricultural Research Academy). During winter, all plots were planted with a local wheat cultivar (*Triticum aestivum L*. Yunza hybid 14, also supplied by Yunnan Agricultural Research Academy). Details of the cultivation of maize and wheat are given in the following sections.

2.2.1 Maize planting

Sowing

Seeds were sown on 19 May 1999, 17 May 2000 and 18 May 2001. The sowing procedure was as follows. The soil was dug smoothly with a Chinese hoe, removing large stones, ridges and any remaining clumps of vegetation. According to different treatments, firstly pits for downslope cultivation and ditches for contour cultivation were dug, secondly seeds were sown (four or six seeds were sown in each pit to ensure the survival of at least two seedlings), then urea, manure and superphosphate were applied (Table 2.1). The pits or ditches were then covered with soil and finally watered with ~300 litres for each plot, applied to the pit or sown areas. Treatment D was the traditional cultivation method in the region, designed to be the control, with seeds planted, as shown in Figure 2.2a. Treatment C was a method with plant spacing on the contour (Figure 2.2 b). Treatment C+P was covered with polythene mulch. A non-permeable 10 μm thick, 0.9 m wide plastic film was used for polythene mulch treatment. A shallow furrow was dug around the perimeter of the area to be mulched, a 0.9 x 3.5 m sheet of plastic was then laid and anchored by bending the edge down into the furrow and covering it with soil (same as Figure 2.2 b).

Treatment C+P+S (*Integrated Contour Cultivation*, *Plastic and straw mulch treatment*, INCOPLAST) was covered with polythene mulch, like treatment C+P, and 9 kg/plot straw mulch (not chopped) was spread evenly between the plastic mulch (Plate 2.2, Figure 2.3). This system is designed to improve yields by plastic mulch and to conserve soil, water and nutrients by the use of contour cultivation and straw mulch. Ridges are shaped to divert water towards the maize roots, beneath the plastic mulch. Treatment C+P+IS was covered with the double wide polythene mulch on the maize rows and then two rows were dug. Then 10 pits were made in wide spacing, to sow soybean seeds (*Glycine max* (L.) Merr. Yunyu 66, supplied by Yunnan Agricultural Research Academy). Less manure and ~1 litre water were applied to each pit. Each soybean pit had four seeds (Figure 2.2c, Plate 2.3).

Downslope cultivation

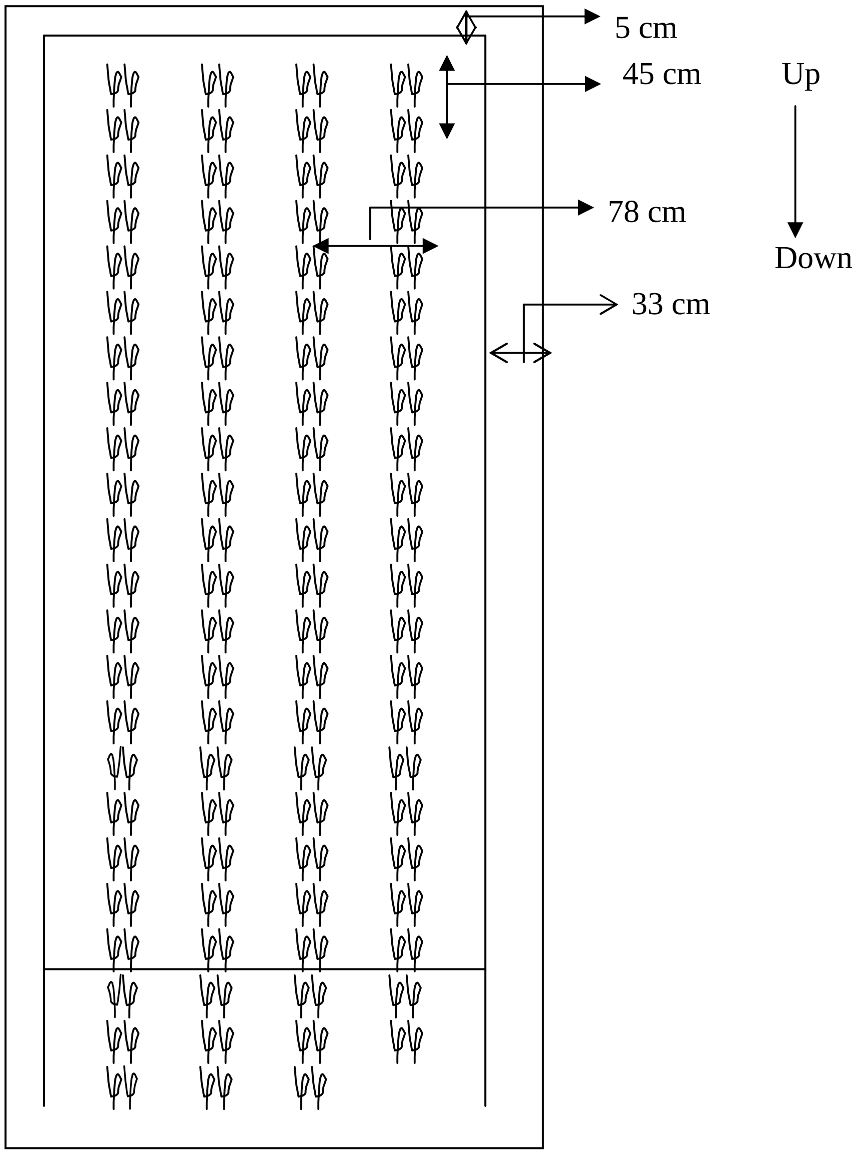


Figure 2.2a. Downslope planting: Treatments D Field arrangement. Maize row space was 0.78 m and pit space was 0.45 m, each plot had 4 rows and in total with 23, 23, 23, 22 seed 'pits,' total no. plants was (23×3+22)×2 = 182, density = 182/30 m^2 = 6.07 plants/m^2 .

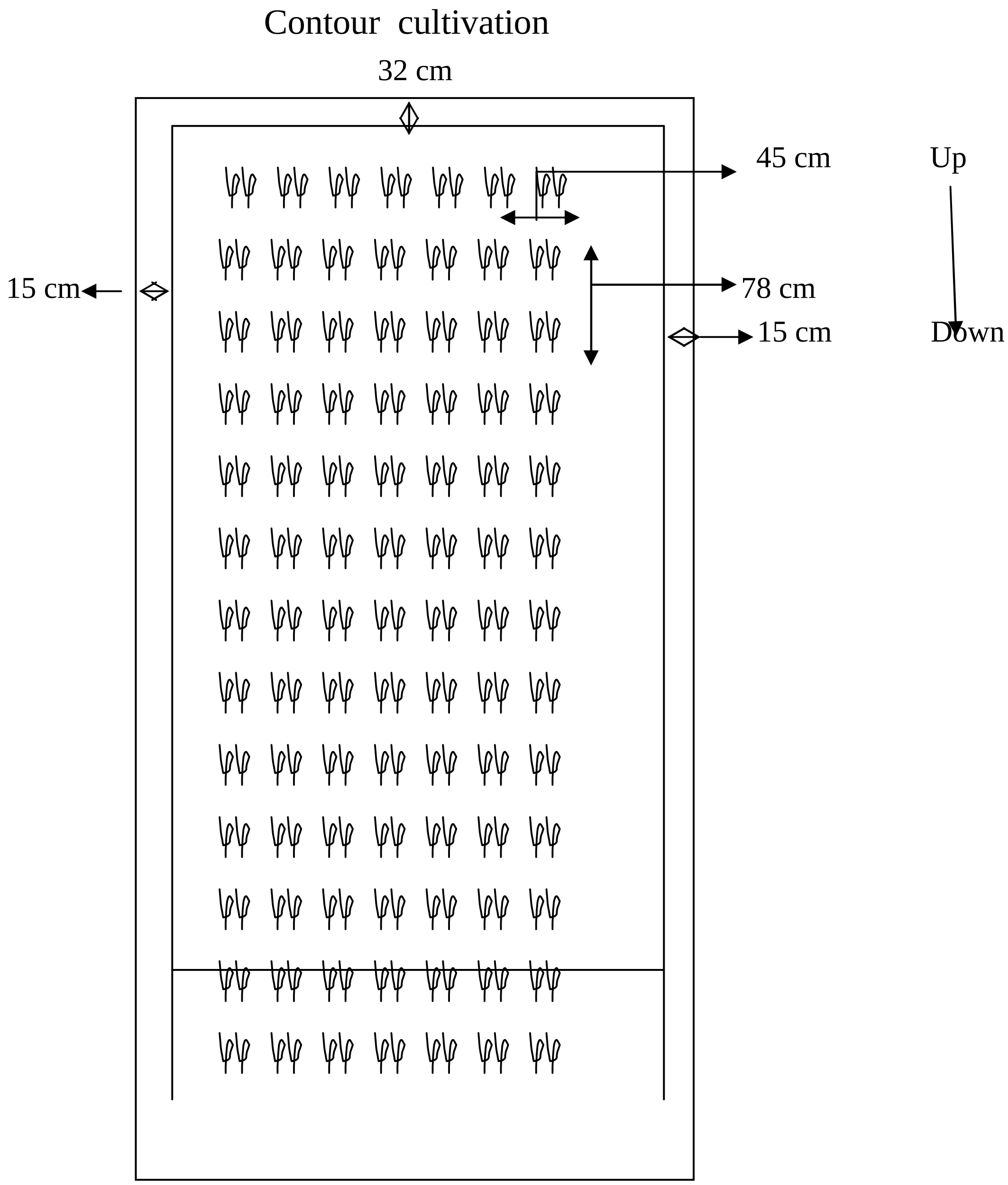


Figure 2.2b. Contour planting: Treatments C, C+P and C+P+S field arrangement. Maize row space was 0.78 m and plant spacing was 0.45 m, each plot had 13 rows and 7 'pits', each 'pit' had two plants. Total no. plants was 13×7×2 = 182, density = 182/30 m^2 = 6.07 plants/m^2.

Intercropping cultivation

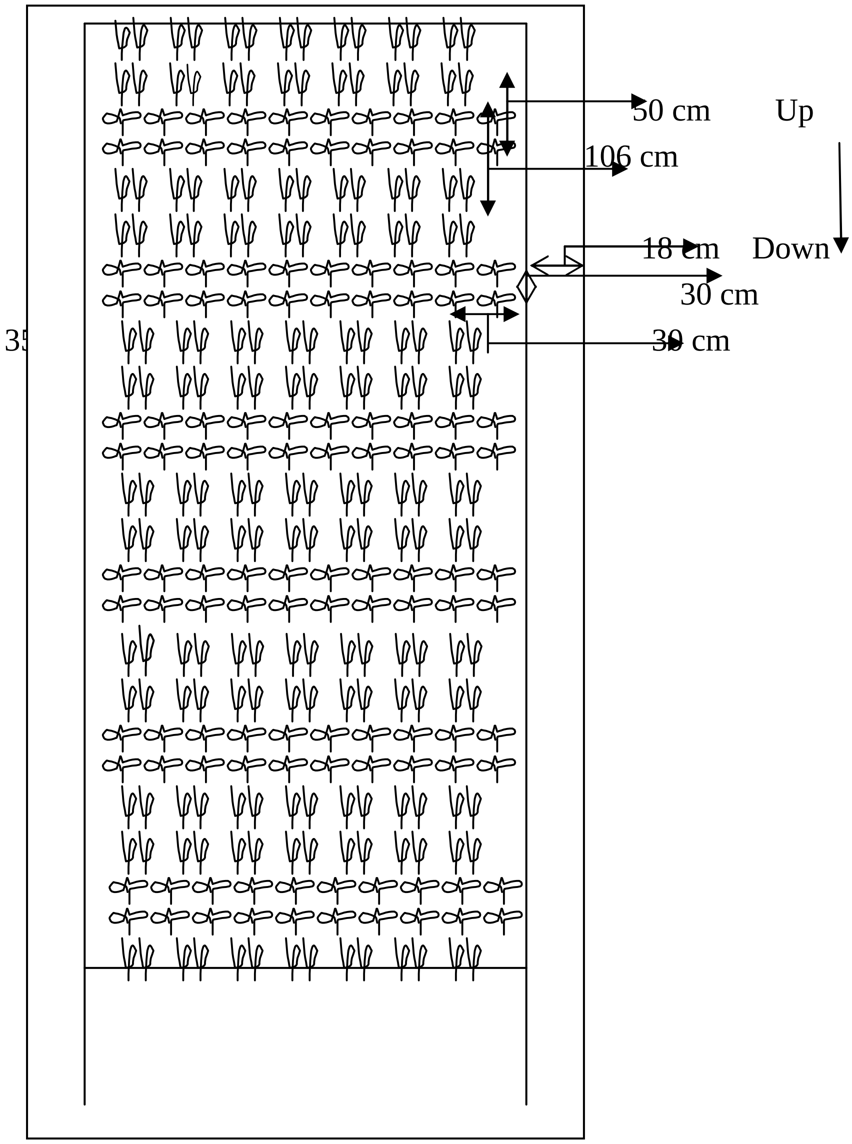


Figure 2.2c. Contour + intercropping planting: Treatment C+P+IS field arrangement. The wide row space was 1.06 m and narrow row space was 0.5 m. The maize plant spacing was 0.45 m and soybean pit space was 0.3 m. Each plot has 13 rows of maize and 12 rows of soybean, and each row has 7 pits of maize (two plants for each 'pit') and 10 pits of soybeans (four plants for each 'pit'). Total maize no. plants was 13×7×2 = 182, density = 182/30 m^2 = 6.07 plants/m^2. Total no. soybean plants is 12×10×4 = 480, density = 480/30 m^2 = 16 plants/ m^2.

Plate 2.2. The polythene and straw mulch plot (INCOPLAST), 9kg/plot straw was distributed evenly between the polythene mulch on each plot

Figure 2.3. Sketch of the INCOPLAST treatment

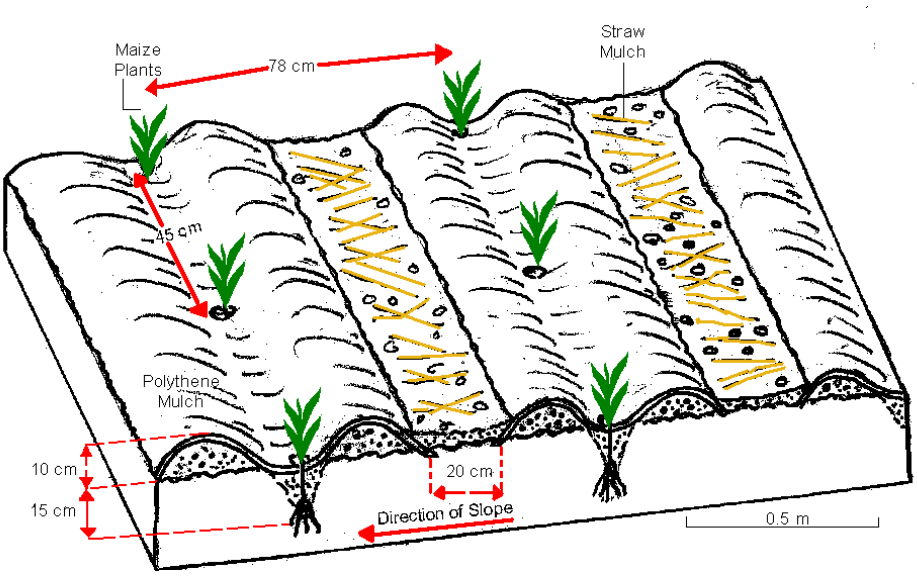


Plate 2.3. The intercropping plot. Between the wide space, two rows of soybean were intercropped

Table 2.1. Application of fertilizers to maize pits

Application	Manure (kg/ha)	Superphosphate (kg/ha)	Urea (kg/ha)
Base fertilizer	15000	300	225
First top dressing	0	0	150
25/06/1999			
23/06/2000			
24/06/2001			
Second top dressing	0	0	300
19/07/1999			
23/07/ 2000			
21/07/2001			

Note* According to laboratory analysis, the manure nutrient contents were as follows: N-1.34%; P-0.17%; K-2.57%; Available N-642.2ppm; Available P-18.13 ppm; Available K-13894.3 ppm; O.M-2.17 and pH 7.0.

In 1999, during the sowing period, no rainfall occurred, so ~300 litres of water were added to each plot. During the growing season, each plot was irrigated with another ~300 litres of water on 30 June, because of dry weather. However, during the 2000 and 2001 maize sowing seasons, it was unnecessary to irrigate, because of sufficient rainfall, and during the whole growing season the plots were not watered.

Thinning and transplanting

For the correct plant density with two plants in each pit, seedlings had to be thinned or transplanted. This was performed on 08/06/1999, and checked on 28/06/1999. In 2000, the first time for thinning or transplanting was on 09/06/2000 and the second time was on 25/06/2000. In 2001, the first thinning or transplanting was on 06/06/ 2001 and second was on 23/06/2001.

Further fertilizer application and weeding

During the three maize growing seasons, in addition to the base fertilizer application following sowing, there were two additional top-dressings. Fertilizer was added to the plots in two doses either side of the plants and then covered with a small amount of soil to prevent ammonium loss (Table 2.1).

Weeding was carried out twice during the maize growing seasons: firstly at the end of June and again at the beginning of August. For the no mulch plot, the Chinese hoe was used for weeding, but for the mulch plots, it was impossible to use the hoe, so this was performed by hand.

Pesticide applications

In 1999 and 2000 for the intercropping plots, the insecticide Deltamethrin (Di Sha Si in Chinese) was used for soybeans, because the soybean leaf was damaged by worms. However, no insecticide was applied to the maize, because there was no evidence of pest damage. In 2001, corn borers damaged the maize shoots, so Deltamethrin was applied to maize and soybean. A 0.5% concentration of Deltamethrin was sprayed on all plants until they were completely covered. The insecticide application was made using a hand-held sprayer.

3.3.2 Wheat planting

In winter 1999 and 2000, all experimental plots were cultivated with wheat to ensure there was sufficient straw for the next maize growing season. A maize/wheat rotation is common in this area of Yunnan.

Sowing

Wheat seeds were planted on the same calendar day (19/10/99 and 19/10/00), using a local variety (Yunza hybrid 14). Before sowing, plots were hoed to ~10 cm depth and evenly tilled to produce a ditch shaped like a trapezoid. For each plot, 27 furrows were dug to the same depth, then the seed was distributed evenly in these ditches. Then the urea, manure and superphosphate were applied to the ditch and then it was covered with soil. The seeds and fertilizer rate are given in Table 2.2.

Table 2.2. Application of fertilizer to wheat plots

Seed rate	180 (kg/ha)		
Fertilizer Method	Manure (kg/ha)	Urea (kg/ha)	Superphosphate (kg/ha)
1999 Base fertilizer (broadcast application)	7500	225	600
2000 Base fertilizer (broadcast application)	6334	225	600
2000 Top dressing fertilizer		75	

In 1999, top-dressing urea was not applied because the wheat grew well. Few investigations were conducted on wheat, except yield evaluation. In 2000, in order to monitor the soil temperature and soil moisture performance during the winter season, measurements were taken on some occasions. Also an additional fertilizer was broadcast two months after sowing and ~500 litres of water was applied to each plot, because of rainfall deficiency after sowing.

2.3 Meteorological measurements

A weather station was established on the roof of a farm building in Kelang village, 500 m from the experimental site in 1997, and the weather data were recorded daily at 0900 by a technician from the village.

The rainfall was measured using a tilting syphon rain gauge with a 200 mm diameter drum. The design was based on a tilting Syphon Gauge, produced by the UK Meteorological office (Shaw, 1988). The chart on the drum was changed daily. Air temperature was recorded automatically using a Casella-pattern themohygrograph and the data were also recorded manually at 0900.

In order to collect accurate weather information for the experiment, an additional automatic weather station (AWS, supplied by Delta-T Ltd Cambridge, UK) was established 50 m away from the experimental site in August 1999 (Plate 2.4). Unfortunately, 1999 and 2000 data were collected incompletely from the data-logger. So the Kelang weather station data was also used. In 2001, the meteorological of both weather stations were used.

At the AWS, rainfall was automatically recorded every 10 min and air temperature, air humidity, wind direction and soil temperature at 15 cm depth were automatically recorded every 30 minutes. The data were downloaded every 2 or 3 weeks. During the rainy season, the silica gel desiccant in the data-logger was checked and replaced if the colour changed from blue to pink, indicating it was hydrated. The daily rainfall, air humidity, air temperature, soil temperature and solar radiation were calculated from these databases from the first day at 0900 to the next day at 0900.

Plate 2.4. A Delta-T weather station and data logger was established 50 m from the experimental site in August 1999

2.4 Soil properties in the experimental plots

2.4.1 Soil temperature.

Soil temperature influences seed germination and directly influences the growth of emerging crops, by affecting mineralization and water absorption (Antonopoulos, 1999). Measurements were made to find comparative differences between treatments. In 1999, during the cropping season, soil temperatures were measured every 20 days (starting 20 days after sowing) at four depths (0, 5, 10, 15 cm) on three occasions (0700-0800, 1400-1500 and 1700-1800). The equipment used was a Whatmart Lo-Temp g-sensor hand-held temperature probe (Huang, 2001). The measurement point was 10-20 cm between two pits. Three positions (top, middle and bottom of the plot) were randomly chosen in one plot. To prevent damaging the thermometer probe, a marked steel pole was used to create a hole to the appropriate depth, then after one minute, a reading was taken on the digital display (°C). All the measurements of C+P, C+P+S and C+P+IS treatments were underneath the polythene mulch. At first, all plots were measured, but it took too long to complete, so for later intervals, measurements were limited to one block.

In 2000 and 2001, soil temperature was measured at 1 and 5 cm depth using Whatman digital soil thermometers supplied by Whatman International Ltd, Maidstone, Kent, UK (Plate 2.5). Five measurements were made on each plot with the same measurement timetable as soil moisture. The measurement time was between 1200-1300 on each occasion. Additionally, in 2001, 12 soil temperature sensors were installed in the plot and the sensors were connected to the data-logger to monitor soil temperature each hour in the different treatments and depths (Plate 2.6).

Plate 2.5. A Whatman digital soil themometers supplied by Whatman International Ltd, Maidstone, Kent, UK, was used to monitor soil temperature at 1 and 5 cm soil depths

Plate 2.6. 12 soil temperature sensors were connected to the data logger during the 2001 maize growing season. Unfortunately, six sensors were vandalized on 06/08/2001

2.4.2 Soil moisture

In 1999, soil moisture was measured gravimetrically in soil samples 20 days after sowing and every 20 days thereafter. Soil samples were taken at three positions (top, middle and bottom of the plot) at 0-5, 5-10 and 10-15 cm depths for each position (Table 2.3). The soil was taken in labelled tins and weighed as soon as possible and oven-dried at 105°C for 48 hours before re-weighing. The percent soil moisture was then calculated using the equation:

$$\text{Soil moisture (\%)} = \frac{\text{Weight of Fresh soil - weight of dried soil}}{\text{Weight of dried soil}} * 100\% \qquad 2(1)$$

In 2000 and 2001, soil moisture was measured using the Theta probe ML2 supplied by Delta-T, Cambridge UK (Milne, 2001). The probe was attached to a Delta-T Theta meter, which contains an internal power supply (Plate 2.7). There is a simple linear relationship between the square root of the dielectric constant ($\sqrt{\varepsilon}$) and volumetric water content (θ) (Whalley, 1993; White *et al.*, 1994).

$$\sqrt{\varepsilon}=a_0+a_1\theta \qquad 2(2)$$

The ML2 has not been used on the experimental site before, so it was calibrated on-site, the calibration procedure was that stated in the user manual (ThetaProbe Soil Moisture Sensor Type ML2 USER MANUAL, 1998):

1: A soil sample was taken with a known volume vessel, disturbing the soil as little as possible. The thetaprobe was inserted into the sample and the reading V_w taken, $\sqrt{\varepsilon_w}$ was calculated using the equation:

$$\sqrt{\varepsilon_w}=1.1+4.44\ V_w \qquad 2(3)$$

Where Vw is the output from the probe (volts).

2: Weigh the moist sample (g)

3: Oven-dry the sample at 105°C for 48 h and weigh the dry soil, insert the Thetaprobe into the dry soil ($\theta \approx 0$) and take the reading (V0) and use equation 2 (3) to calculate $\sqrt{\varepsilon_0}$, this equals a_0.

4: Calculate the volumetric water content θw

$$\theta_w = \frac{W_w - W_0}{L} \qquad 2(4)$$

Then

$$a_1 = \frac{\sqrt{\varepsilon_w} - \sqrt{\varepsilon_0}}{\theta_w} \qquad 2(5)$$

5: Finally, inverting equation 2(2) and substituting from equation 2(3), the water content determined from a calibrated Thetaprobe is calculated:

$$\theta = \frac{(1.1+4.44V) - a_0}{a_1} \quad (m^3.m^{-3}) \qquad 2(6)$$

Five measurements on each plot were made every two weeks, with more frequent measurements during early stages and after seeding and thinning. Two positions for soil moisture measurement in C+P, C+P+S, C+P+IS were used, one position was under the polythene, ~10 cm between two pits. Another was ~3-5 cm from the plant base.

Plate 2.7. Theta probe ML2 was used to monitor soil moisture during the 2000 and 2001 maize growing seasons

Soil matric potential was also measured using Delta-T Equitensiometers. This is the negative pressure (or suction) required to extract water from the matrix of soil particles. It is an important indicator of plant water stress. The Equitensiometers work on similar principles to soil moisture, the sensor comprises a ThetaProbe embedded into a specially formulated matric material. The water content of this material rapidly reaches equilibrium with the metric potential of the surrounding soil, and the absorbed water is detected by the ThetaProbe. Each probe is supplied with its own calibration curve for converting volts into kp_a. Three soil matric potential probes were buried in the middle of plot 8 (under straw mulch), plot 11 (under the contour cultivation no mulch) and plot 13 (under polythene mulch). They were buried at 10 cm depth (Plate 2.8) at a slight angle and pre-wetted according to supplier's recommendations, then excavated soil was used to fill the gaps around the probe, to ensure full contact between the probe and its surroundings.

Plate 2.8. After harvest, the Delta-T Equitensiometers was excavated using the shovel

Additionally, in 2001, the profile probe PR1 (supplied by Delta-T Ltd.) was established in the middle of each plot before sowing. The manual recommended disturbing soil as little as possible, but unfortunately, after using the auger to make a guide hole, the soil was too hard to allow the access tube to be inserted directly. Therefore 50 cm depth of soil had to be opened and the other 50 cm depth opened wider by auger. A 1 m hole was created by this way and then the profile probe tube was inserted into the hole, excavated soil was used to fill the gaps around the tube, to ensure full contact between the tube and its surroundings (Plate 2.9).

Plate 2.9. The profile probe tube was established before the sowing

A: Profile probe inserted in tube.

B: Access tube before installation in soil.

C: Auger

The Profile Probe type PR1 is a precision soil moisture probe able to obtain moisture readings at different depths within a vertical soil profile. Each Profile Probe has multiple sensors. The profile probe consists of a sealed composite ~25 mm diameter rod, with electronic sensors (in the form of a pair of stainless steel rings) arranged at fixed intervals along its length. When taking a reading with the HH2 moisture meter, the probe is inserted into the access tube. The access tubes have specially constructed thin wall tubes, which maximize the penetration of the electromagnetic field into the surrounding soil (Plate 2.10). Calibration was as for the Theta probe.

Plate 2.10. Profile probe taken readings from the access tube, which had been installed in the soil

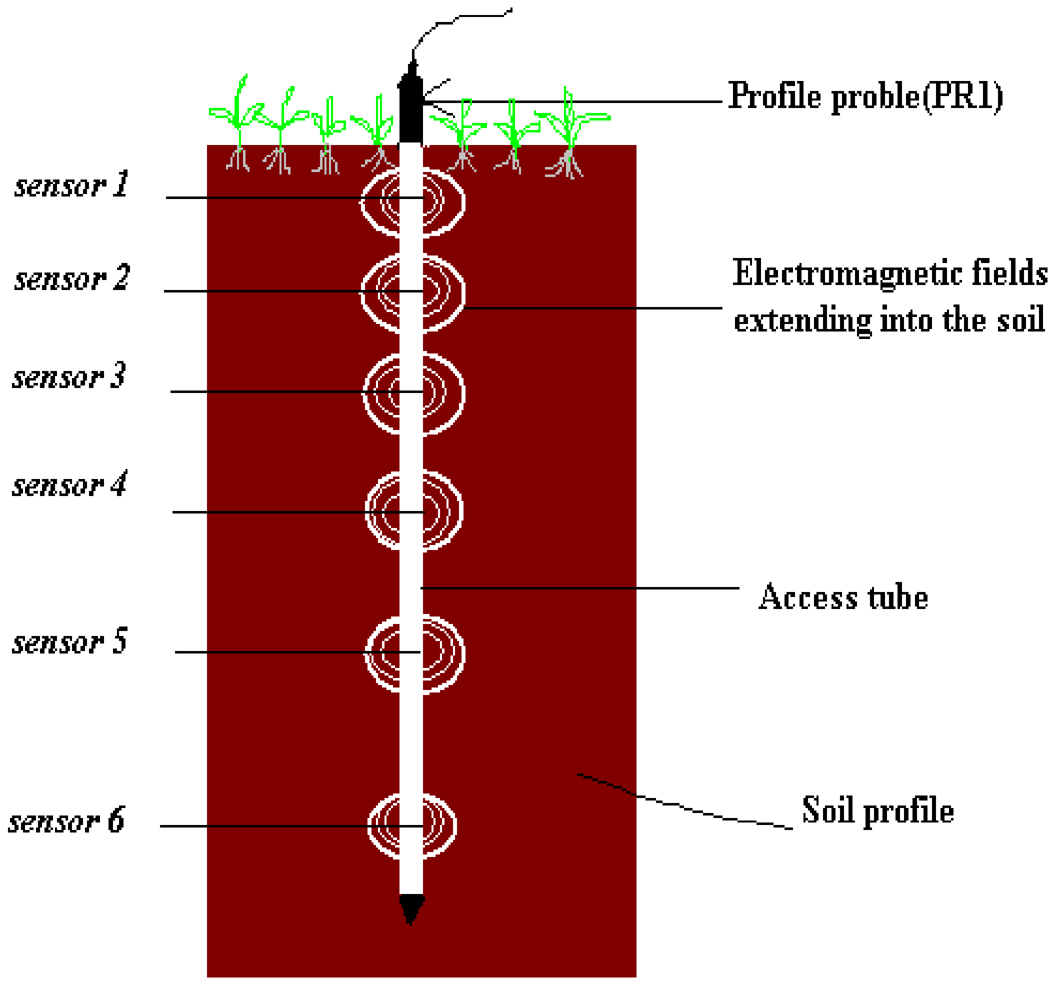


Table 2.3 Schedule of soil moisture and soil temperature measurements for the 1999, 2000 and 2001 seasons

		Measurements									
Year		1	2	3	4	5	6	7	8	9	10
1999	Date	9/6	30/6	19/7	8/8	29/8	18/9				
	DAS*	20	40	60	80	100	120				
2000	Date	26/5	9/6	16/6	27/6	11/7	24/7	6/8	21/8	5/9	20/9
	DAS*	9	23	30	43	56	69	82	97	112	127
2001	Date	27/5	6/6	13/6	23/6	9/7	24/7	9/8	24/8	9/9	24/9
	DAS*	9	19	26	36	52	67	82	97	112	127

DAS* Days after sowing**.**

2.4.3 Soil bulk density

Soil bulk density is the weight of soil within a given volume. Soil bulk density (g cm^{-3}) was measured at the early crop growth stage and two or three weeks before harvest, using soil bulk density tins (100 cm^{3}). On each plot, three places were randomly selected between 1 m from the top edge and 1 m from the bottom edge of the plot. Samples were taken 36 days after sowing in 1999, 40 days after sowing in 2000 and 35 days after sowing in 2001. In 1999, samples were taken 19 days before harvesting, and 12 days before harvesting in both 2000 and 2001. All tins were labelled and weighed before samples were taken. Samples were taken by gently hammering the bulk density tins into the soil to a depth of 0-10 and 10-20 cm. The tin was gently removed, carefully trimmed, weighed and oven-dried at 105°C. The oven-dry weight was divided by the volume of the circle knife to obtain bulk density (g cm^{-3}) (Rowell, 1996). Bulk density was calculated according to equation:

Dry bulk density (g cm^{-3}) = Mass of oven dry soil (g)/volume of cylinder (cm^{3})   2(7)

(In 1999, 0-10 cm depth soil bulk density was measured, but not 10-20 cm soil depth because of a shortage of tins).

2.5 Chemical analysis

Soil Sampling

Topsoil samples (0-15 cm) was taken from each plot just before sowing (19/05/1999, 17/05/2000 and 18/05/2001) to give soil data at the onset of the experiment and after harvest (07/10/1999 and 07/10/2000) to monitor changes. Three samples were taken from the top, bottom and a composite of each plot. For top and bottom samples, three positions were randomly collected from the top and bottom of the plot, respectively. Therefore samples were halved and quartered, thoroughly combined and mixed, and then a ~1 kg sample was taken from each collective bulk. For composite soil samples, five positions forming a S-pattern in the plot were sampled, these five samples were combined thoroughly, mixed and a composite ~1 kg sample taken. All soil samples were taken to the laboratory for air-drying.

The final soil sample taken (07/10/2001) was different from the previous ones. In order to compare the difference within treatments, the soil sample taken was adjusted: for the **C+P** treatment, two samples were taken for each plot, one was under the polythene and another was between the polythene. For the **C+P+S** treatment, two samples were taken from each plot, one was under polythene and another under straw. For the **C+P+IS** treatment, two samples were taken from each plot, one was under polythene and another under the soybean row. For the **D** and **C** treatments, only one composite sample was taken from each plot (Table 2.4).

Sample preparation

Before grinding, all samples were air-dried and all stones and large pieces of straw, stem and roots were removed. Soil samples were ground to pass the 1.0 and 0.25 mm sieve meshes, to analyse soil pH, organic matter, total nitrogen, total phosphorus, total potassium, available nitrogen, available phosphorus and available potassium. Soil particles <1.0 mm were used to analyse available nutrients and <0.25 mm for total nutrient concentrations (Shi, 1988).

Table 2.4. Soil samples collected from the experimental plots

Year	Soils	Date taken	No. samples
1999	Soil 1	14/5/1999	45
	Soil 2	18/10/1999	45
2000	Soil 1	10/5/2000	45
	Soil 2	18/10/2000	45
2001	Soil 1	10/5/2001	45
	Soil 2	07/10/2001	24

2.5.1 Total nitrogen

Soil nitrogen occurs in the forms of organic compounds, nitrite and nitrate anions and ammonium ions (Wild, 1998) total soil N refers to the sum of all three forms of N.

Procedure:

This was determined by a variation of the Kjeldahl method (Shi, 1988), which consisted of two steps: (a) Digestion: 1 g of <0.25 mm soil was weighed into a 100 ml digestion tube, ~2 ml distilled water was added along with 1.85 g of $K_2SO_4.CuSO_4.Se$ salt mixture (ratio of 100:10:1,w/w/w, consisting of 100 g potassium sulphate, 10 g copper sulphate and 1 g selenium). Then 5 ml of concentrated sulphuric acid (H_2SO_4) was added and the sample digested in the digest oven (Plate 2.11) until a shallow blue-green colour was obtained, indicating the absence of carbonaceous material. The mixture was heated for one hour more, to ensure that all organic N had turned to ammonium sulphate. The liquid was cooled and diluted to 30 ml with distilled water and was prepared for distillation. (b) Distillation: a 125 ml Erlenmeyer flask containing 5 ml 2% H_3BO_3 indicator solution was placed under the condenser of the distillation apparatus to absorb the ammonia. The distillation flask was held at a 45° angle and ~20 ml of 10 N NaOH poured down the neck, so that the alkali could reach the bottom of the flask without mixing appreciably with digested material.

Plate 2.11. Nitrogen was digested in the oven in the fume cupboard in the Department of Soil Chemistry at Yunnan Agricultural University

The flask was then attached to the distillation unit (Plate 2.12). When ~50 ml of distillate was collected, the receiver flask was lowered, so that the end of the condenser was above the surface of the distillate. After rinsing the end of the condenser with distilled water, the flask was removed and distillation ceased. Ammonium-N in the distillate was determined along with a blank by titration with 0.02N sulphuric acid. The colour changed at the end point from green-grey to brown-red. Percent N was calculated as follows:

Total N (%) = $[(v-v_0)\ N*0.014/w]\ *100\%$ 2(8)

Where:

V = Volume of H_2SO_4 used to titrate the sample (ml)
V_0 = Volume of H_2SO_4 used to titrate the blank (ml)
N = Concentration of H_2SO_4
W = Dry weight of soil (g).

Plate 2.12. Nitrogen distillation unit in the Department of Soil Chemistry, Yunnan Agricultural University, China

2.5.2 Total Phosphorus and Potassium

Total phosphorus refers to both inorganic and organic phosphorus in the soil. Total phosphorus and total potassium were measured using a method in which soil is ignited in a sodium hydroxide/ethanol solution (Shi, 1988). Total P and K were measured as follows. A 0.25 g sample of air-dried soil (particle size <0.25 mm) was weighed into a silver crucible, with a few drops of ethanol to help diffuse the particles and 2 g of sodium hydroxide added. The sample was placed in the furnace for 15 minutes at 450°C and another 15 minutes at 720°C (Plate 2.13).

Plate 2.13. Silver crucible with the soil sample and sodium hydroxide heated in the muffle furnace

The crucible was removed from the furnace and 10 ml distilled water added to dissolve the mixture and the solution was transferred to a 50 ml volumetric flask. The crucible was washed with 0.4N H_2SO_4 several times, until the total volume reached ~40 ml. Five drops of 1:1 HCl and 5 ml 9N H_2SO_4 were placed in the flask. The solution was made up to the mark using distilled water, then filtered and the filtrate collected. K in the solution is measured using flame photometry. Five ml of the filtrate was pipetted into a 50 ml volumetric flask. About 20 ml distilled water was added, the sample was shaken and made up to the mark with distilled water. P in the solution was measured using the spectrophotometer at 700 nm.

Total phosphorus calibration curve

Preparation of a calibration curve involved weighing 0.2195 g monobasic potassium phosphate (KH_2PO_4), and dissolving and diluting with 1 litre of distilled water. This solution contained 50 ppm phosphorus. A set of standards was prepared by placing 0, 0.1, 0.2, 0.4, 0.6, 0.8, 1.0 ppm solutions in 50 ml volumetric flasks. This was followed by addition of 5 ml molybdate-vanadate solution and then allowing them to mix and stand for 30 minutes. Percent transmittance was measured at 700 nm and a calibration curve was constructed. The amount of total P in the soil was determined by the equation:

Total P (%) = (Conc. solution (ppm)*volume of solution (ml)*dilution*100/(g)* 10^6)*100% 2(9)

Total potassium calibration curve

A potassium stock solution was prepared by dissolving 0.1907 g of KCl (previously dried at 110°C) in distilled water and diluting to 1 L. The solution contained 100 ppm K. A 10 ml extract was then mixed and made to a final volume of 100 ml with distilled water. The mixture was shaken for 10 minutes and K determined using a flame photometer calibrated with standard solutions (Plate 2.14).

Plate 2.14. Potassium was measured by flame-photometer (supplied by the Shanghai Equipment Company)

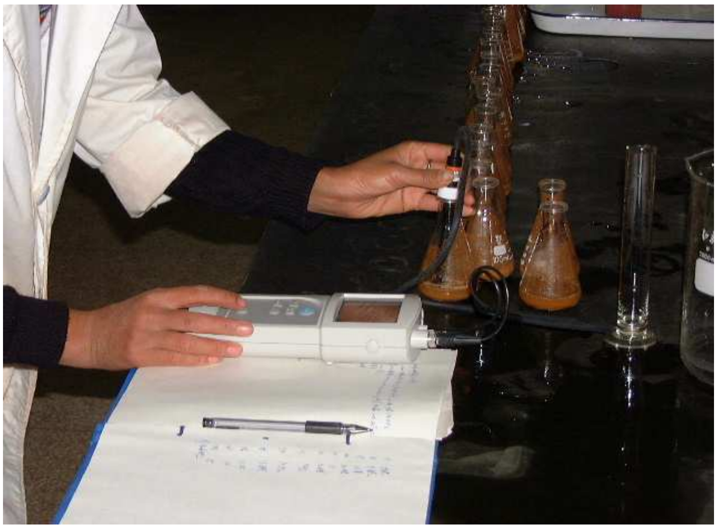
The amount of total K in the soil samples was calculated using the equation:

Total K (%) = (Conc. of solution (ppm) * volume of filtrate (ml)* dilution * 100 / W (g) * 10^6)*100% 2(10)

2.5.3 Soil pH

Soil pH was measured using a Whatman pH meter. A sample of 10 g of air-dried soil with a particle size <1.0 mm was weighed into a 50 ml glass beaker and 25 ml of distilled water added. The soil and liquid were mixed thoroughly and left to stand for 10 minutes. The pH meter was calibrated using buffer solutions of pH 4 and 7, then the pH probe was inserted into the beaker and the soil suspension was stirred by swirling the electrodes slightly (Plate 2.15). Immediately after, the pH value was read on the standardized pH meter.

Plate 2.15. Soil pH reading taken with Whatman pH Meter



2.5.4 Soil organic carbon

There is no universally recognized method to measure soil organic matter. However, organic carbon content can be determined. The organic matter content can be estimated by assuming total organic matter has 58% organic carbon content (Rowell, 1996). Organic carbon was analysed using the Walkley-Black method with heating (Walkley and Black, 1934). The procedure is: 0.1000-0.5000 g of air-dried soil (particle size <0.25 mm) was weighed into a glass tube. Exactly 10 ml of 0.4 N $K_2Cr_2O_7$-H_2SO_4 was added to each tube. Then a small funnel was inserted to cover the opening of each tube. The tubes were placed in a vessel containing boiling plant oil with a temperature of ~170-180°C. When the liquid in the tubes boiled, the time was noted and the liquid boiled for 5 minutes. The tubes were taken out and the liquid transferred to a 250 ml flask, by washing with 60-70 ml of distilled water. Then 2-3 drops of indicator solution were added and the solution titrated with standard 0.2 N Fe_2SO_4. The end point of the reaction is a bright green colour and the volume of Fe_2SO_4 used in titration was recorded to calculate organic carbon, and then organic matter %. The equation is:

Organic matter (%)= [(V_0-V)* Cons of solution (N))]/W 2(11)

Where: $V_{0:}$ the volume of Fe_2SO_4 used to titrate the blank (ml)

V: the volume of Fe_2SO_4 used to titrate the sample (ml)

N: Concentration of Fe_2SO (ppm)

W: Dry weight of soil (g).

2.5.5 Available Nitrogen

Available nitrogen was analysed using a variation of the Conway method (Shi, 1988). The method transforms nitrate and nitrite into ammonia, this can be measured by titration in the same way as total N. A sample of 2.00 g of <1.0 mm air-dried soil was placed in the outer ring of the Conway vessel, and 1.00 g of $FeSO_4$ added into the outer ring. 2 ml 2% H_2BO_3 was added with pH indicator into the inner ring and 10 ml of 1.8 N NaOH added to the outer ring. The lid was placed on the Conway vessel using glue around the edge to ensure a good seal (Plate 2.16). The Conway vessel was placed in an oven at 40°C for 24 hours.

Plate 2.16. Conway vessel for available nitrogen. H_2BO_3 in the inner ring and soil sample, $FeSO_4$ and NaOH in the outer ring

The lid was removed and the solution titrated in the inner ring with 0.02 N H_2SO_4. The volume of acid used in the titration was recorded, in order to calculate the available nitrogen content. The equation was as follows:

N (ppm) = (Total N (%)=[(v-v_0)N*14/w] *1000 2(12)

Where: V = Volume of H_2SO_4 used to titrate the sample (ml)

V_0 = Volume of H_2SO_4 used to titrate the blank (ml)

N = Concentration of H_2SO_4 (ppm)

14 = one equivalent of N

W = Dry weight of soil (g).

2.5.6 Available Phosphorus

Available Phosphorus was measured using the Olsen method (Olsen and Sommers, 1982), extracted using $NaHCO_3$. A sample of 2.50 g of <1.0 mm air-dried soil was weighed into a plastic bottle and a spoonful of pure carbon added. 50 ml of 0.5 M $NaHCO_3$ was added and pH adjusted to 8.5. The mixture was shaken for half an hour and then filtered and the filtrate collected. 10 ml of the filtrate was pipetted into a 50 ml volumetric flask and ~35 ml distilled water added and the mixture shook. 5 ml mixed reagent (molybdate solution) was added and made up to the mark with distilled water. Sets of standards were made up ranging from 0-0.5 ppm and P was measured using a spectrophotometer at 700 nm (Plate 2.17).

Plate 2.17. Spectrophotometer used for the P measurements (supplied by Shanghai First Laboratory Facility Factory)

The equation for available P in the soil was:

$$\text{Available P (ppm)} = \frac{\text{Solution conc.} \times \text{volume of solution (ml)} \times \text{dilution}}{\text{W (g)}} \qquad 2(13)$$

2.5.7 Available Potassium

Extraction was carried out with ammonium acetate. 5.00 g of <1.0 mm air-dried soil was weighed into a plastic bottle and 50 ml of 1N ammonium acetate solution added and pH adjusted to 7. The mixture was shaken for half an hour, filtered and the filtrate collected. The K concentration in the filtrate was measured using a flame photometer.

A range of standards from 0-60 ppm was made up using ammonium acetate solution and a stock solution of 100 ppm K. K concentration in the samples was determined from the standards calibration curve. The equation for available K was:

$$\text{K (ppm)} = \frac{\text{Solution conc.} \times \text{volume of solution (ml)} \times \text{dilution}}{\text{W (g)}} \qquad 2(14)$$

2.5.8 Other elemental analysis

In addition, other elements (Ca, Mg, Fe, Cu and Zn) were analysed at the University of Wolverhampton, using an Inductively Coupled Plasma Emission Spectrophotometer (Assembled IRIS Advantage Spectrometer). The equipment consists of two major components: (1) the main spectrometer, containing a computer-controlled polychromatic, fully automated inductively coupled plasma emission source, complete with built-in coolant re-circulator, a refrigeration unit for the CID detector, a power unit and (2) a data acquisition system, including the host computer and printer.

From the manual, the theory of ICP is that liquid samples are introduced into the aerosol discharge as an aerosol suspended in argon gas. This sample aerosol is carried through the centre tube of the three quartz tubes comprising the torch assembly. The sample aerosol stream passes through the centre of the toroidal plasma discharge, where it is desolvated and atomized, and the resultant element atoms and ions are excited. After excitation the atoms comprising the sample emit light at their characteristic wavelengths. This light is transmitted by the optical system to the CID detector (Soltanpour *et al.*, 1982).

Studies have shown that the amount of extractable micronutrients from soil is affected largely by the degree of crusting (Soltanpour *et al.*, 1976; 1979). The Colorado State University Soil Testing Laboratory recommended the standard soil particle analysis is to pass soil through a 2.0 mm sieve after mild crusting. For this analysis, <1.0 mm particles which had been ground at Yunnan Agricultural University were used, so just a relative value was determined, not an absolute value. The objective was to compare elemental concentrations among the different treatments. The samples included the soil samples of the beginning and final year.

For the extraction, Soltanpour *et al.* (1979) developed a 1 M NH_4HNO_3-0.005M DTPA (AB-DTPA) solution for simultaneous extraction of Cu, Fe, K, Mn and Zn from the soil. This method routinely analyses the soil saturation extracts simultaneously for Ca, K, Mg and Na (Soltanpour *et al.*, 1982).

Prior to any chemical testing, all equipment was acid washed in 10% HNO_3, and then rinsed in distilled water. The determination of the multi-elements concentration consists of two steps: firstly extraction, followed by ICP analysis.
The procedure was as follows:

1. Prepare 1 M NH_4HNO_3-0.005M DTPA (AB-DTPA) solution
1.87 g of DTPA (diethylenetriaminepentaacetic acid) is added to 800 ml of de-ionized water (DDW), and ~2 ml of 1:1 NH_4OH added to facilitate dissolution and prevent effervescence. This was shaken until most DTPA dissolved, then 79.06 g of NH_4HNO_3 was added and stirred gently until dissolved. Then pH was adjusted to 7.6, with either HCl or NH_4OH. The solution was diluted to 1.0 litre with DDW. This solution is unstable with regard to pH and thus it is preferable to use a fresh solution.

2. Sample extraction
10 g of <1.0 mm soil is weighed into a 125 ml conical flask and 20 ml of AB-DTPA solution added. This was shaken for 15 min at 180 cycles/min with flasks kept open. The extracts were filtered through Whatman No. 42 filter paper. A 2 ml aliquot of the extract was taken, and 0.25 ml conc. HNO_3 was added. This mixture was shaken for 10 min to remove carbonate-bicarbonate matrix, to prevent clogging of the capillary tip in the nebulizer. This solution was then ready for simultaneous multi-elemental determination. Each set of extractions had two blanks, containing only extractant solution.

3. To determine Ca, Mg, Fe, Zn and Cu concentrations, solutions were passed through the Inductively Coupled Plasma (ICP) spectrometer. Standard concentrations of 1 and 10 ppm were prepared and used to calibrate the instrument. The flush time was set at 35 seconds and the rinse time at 10 seconds. The chosen wavelengths were Ca (1840 nm), Mg (2802 nm), Zn (2138 nm), Cu (2247 nm) and Fe (2382 nm).

The equation for these elements determination were:

$$\text{Ca, Mg (mg 100 g}^{-1}) = \frac{\text{C (ppm)} \times \text{Vol of solution (ml)} \times \text{dilution}}{10^4 \times \text{sample weight (g)}} \times 10^3 \qquad 2\,(15)$$

$$\text{Fe, Cu and Zn (mg kg}^{-1}\text{)} = \frac{\text{C (ppm)} \times \text{Vol of solution (ml)} \times \text{dilution}}{\text{sample weight (g)}} \qquad 2(16)$$

where C (ppm) is the concentration reading from the instrument.

Table 2.5 presents a summary of measured soil physical and chemical properties.

Table 2.5. Summary of measured soil physical and chemical properties

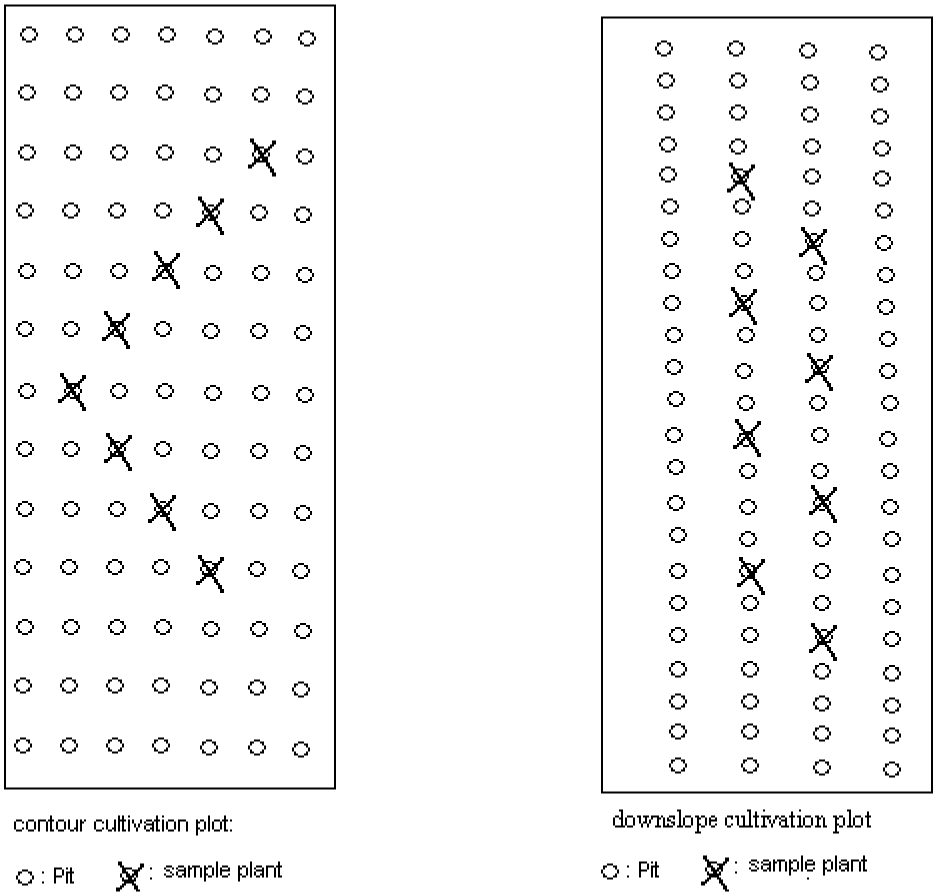
Property measured	Method employed
Physical:	
Soil temperature	Soil thermometers
Soil moisture	Gravimetric determination
Bulk density	Bulk density corer
Chemical:	
Total N	Semi-micro Kjeldahl
Total P	Fusion in hydroxide/ethanols solution at high temperature
Total K	Fusion in hydroxide/ethanols solution at high temperature
Available N	Conway vessel
Available P	Olsen, extract with sodium bicarbonate
Available K	Extract with ammonium acetate
pH	pH meter with 1:2.5 soil:water ratio
Organic carbon	Walkley-Black method (with hot boiling oil)
Ca, Mg, Zn, Cu and Fe	AB-DTPA extraction and determined by ICP

2.6 Crop growth

Plant height and leaf area measurement

Crop growth data were collected during the three growing seasons, beginning after seedling thinning and continuing until harvest. In each pit, the plants were thinned to two plants. After seedlings were thinned, plant height and leaf area were measured every 15 days. Eight plants were randomly selected in a V shape on the contour cultivated plots and a Z shape on down-slope cultivated plots within the inner two rows, avoiding the edges. The plants were tagged for repeat measurements (Figure 2.4).

Figure 2.4. Plants selected for growth measurements and yield estimates on contour and up-down cultivated plot:



Measurements began 20 days after planting in 1999, 40 days after planting in 2000 and 35 days after planting in 2001. In 1999, the first measurements were taken on 8 randomly selected plants, because the plants had not been thinned and from the second time (after thinning), the measurements were carried out on the 8 tagged plants. Based on the 1999 experience and results, the measurements in 2000 and 2001 started after the seedling had been thinned and the samples were chosen and tagged. In 1999 and 2000, plant height was measured at the tip of the largest leaf and in 2001 to the tip of the youngest fully expanded leaf (T.J. Hocking, pers. comm, 2001).

For green leaf area, leaf length (L) and leaf width (W) were measured and leaf area estimated from L×W×0.75. Individual leaf area was calculated based on the leaf length (L), maximum width (W) and a correction factor (McKee, 1964). Leaf area = L* W* 0.75.

Heavy hail in early August 2001 damaged the plant leaf and made the measurements more difficult or impossible to continue (Plate 2.18), but in order to estimate hail damage, another measurement was assessed.

Plate 2.18. Heavy hail on 08/08/01 damaged the maize leaves

Green leaf area index (LAI) was calculated using the equation:

$$GLAI = \frac{\text{Leaf area per plant (LA)}}{\text{Area of growth occupied by the plant}} = \frac{(LA)}{1/D} \qquad 2(17)$$

Where D = plant density

The Green Leaf Area Duration (GLAD) is calculated by using the GLAI curve during the whole growing stage, and calculating the total area (weight) under the curve by dividing the area (weight) into a certain square, then multiplying the days between the measurements gives GLAD, using the equation:

$$GLAD\ (day) = \frac{\text{Area (weight) under GLAI} \times \text{days between the measurements}}{\text{Area (weight) of selected squares}} \qquad 2(18)$$

Yield

After harvesting, economic yield, biomass production and yield components were determined.

Harvest procedures

At harvest, the pre-selected 8 tagged plants were measured. The plants were cut at the stem base and taken to the laboratory for detailed analysis. Plant height was measured again in 1999, but not in 2000 and 2001, and the number of cobs per plant recorded.

The leaves were stripped from their stems, and the stem girth between the fourth and fifth internode was recorded for each plant. Cob girth, the number of rows and the number of grains of two symmetric rows per cob were also recorded. The weights of fresh cob, fresh grains after they were separated from the cob centre and the leaf and stem combined per plant were measured before being oven-dried at 78-80°C for 48 hrs. After drying, the components were reweighed and grain dry weight was recorded, together with 1000-grain weight (Plate 2.19). The weight ratio of dry grain and fresh cob (GCR) was then calculated. This ratio is for the plot yield calculation.

Plate 2.19. 1000 grain weight counting on randomly selected samples

The grain yield was calculated using two methods: one was from actual plot total of fresh cob weight, adjusted to grain weight at 13% moisture using the GCR from the 8 sampled plants and second from eight tagged plants dry grain weight.

The equations were:

$$\text{Yield 1 (kg/ha)} = \frac{\text{Actual plot fresh cobs weight} \times \text{GCR} \times 1.13}{30} \times 10000 \qquad 2(19)$$

Where: GCR - was ratio of dry grain weight and fresh cob weight
1.13 - adjusted 13% moisture)
30- was the area for one plot (30 m^2)
10000- is to adjust to 1 hectare.

$$\text{Yield 2 (kg/ha)} = (\text{dry grain weight (per plant)} \times 1.13 \times 182 / 30) \times 10000 \qquad 2(20)$$

(1.13- was added 13% moisture. 182- was the density for one plot. 30-was the area of one plot. 10000- is to adjust to 1 hectare).

Other plot measurements

In addition to total fresh cob weights, total fresh weight of leaves and stems were measured (Plate 2.20).

Plate 2.20. Farmers help weigh the total fresh leaf and stem on-site

In Plate 2.20, the cultivar used in the research is still semi-green at harvest, making it more useful as forage.

Soybean investigation

During the soybean-growing season, plant height and leaf numbers were measured to evaluate soybean growth performance and the final yield was assessed. A summary of maize parameters measured is given in Table 2.6.

Table 2.6. Yield and biomass parameters used for assessment of maize productivity

Parameter	Calculation	Notation
Total fresh wt. cobs in plot (kg)	_	A
Total fresh wt. Leaves+ stems in plot (kg)	_	B
Measured parameters:		
8 tag sample plants		
Total no. cobs	_	C
Fresh wt. cobs (g)	_	D
Fresh wt. grains (g)	_	E
Fresh wt. leaves + stems (g)	_	F
Dry wt. cobs (g)	_	G
Dry wt. leaves+ stems (g)	_	H
Dry wt. cob centres (g)	_	I
Dry wt. grain only (g)	_	J
Stem girth (cm)	_	K
Cob length (cm)	_	L
Cob girth (cm)	_	M
No grain rows per cob	_	N
No. grains of 2 symmetrical rows/cob	_	O
1000 grain wt. (g)	_	P
Calculated parameters:		
The ratio of dry grain and fresh cob	J/D	Q
Total wt. dry grain in plot (kg)	(A+D/1000) ×Q	R

2.7 Net Income

Before evaluating the net income of different cultivations, the input costs must be estimated. Estimated input and labour costs are given in Tables 2.7 and 2.8. Total cost included the cost of seeds, fertilizer, polythene and labour. The cost of manure was ignored, so well as the harvest crop stem and leaf. Labour of the contour cultivation treatment was the control, the value was set at 1. Downslope cultivation without mulch could save 30% of labour compared with contour cultivation, the value was 0.7. For contour cultivation with polythene mulch, it took twice as much labour compared with contour cultivation with no mulch, thus the value was 2. The treatments of INCOPLAST and intercropping with polythene mulch took 20% more labour than just with polythene mulch, thus the value was 2.2. The labour of irrigation, applying fertilizers and harvesting were assumed the same for all treatments. The labour needs for different practices are listed in Table 2.7.

Table 2.7. Material and labour cost and market prices of the products in 2000, together with labour cost (the price based on the local village market)

Items	Yuan*/kg	Kg/ha	Yuan/ha
Maize seed	8.0	33.3	266.4
Soybean seed	6.0	66.6	399.6
Super-phosphate	0.495	300	148.5
Urea	1.485	675	1002.4
Polythene	8.0	67	536
Straw	0.1	3000	300
Maize market price	0.8		
Soybean market price	2.0		
Labour	15 (Yuan/day)		

*Where £1 = 12.274 Yuan (26/08/02).

Table 2.8. Labour (person.day) for cultivation on the experiments (labour/ha)

Treatments	D	C	C+P	C+P+S	C+P+IS
Preparation	22	22	22	22	22
Sowing	19	27	54	60	60
Irrigation	22	22	22	22	22
Weeding 1	15	22	0	0	0
Weeding 2	16	22	0	0	0
First dressing	22	22	22	22	22
Second dressing	22	22	22	22	22
Harvest	44	44	44	44	44
Remove polythene	0	0	15	15	15
Sum	181	203	201	207	207
Labour cost (Yuan)	2715	3045	3015	3105	3105

2.8 Statistical analysis

The data were analysed by SPSS (version 10.0 for Windows). All the means and standard errors were described. Two-way (to analyse block and treatment differences) or one-way (to analyse treatments differences) were carried out on the plot means. LSD and Duncan's significant differences were established, to identify significant means within the data.

Chapter 3 Results

Introduction

In this Chapter, three years of maize experiments and two years of winter wheat experiments are presented with statistical analysis. For most data, analysis took the form of one way Analysis of Variance (ANOVA), then using a test for Least Significant Difference (LSD). For Green Leaf Area Index (LAI) the repeat measurement method was used to check for significant differences over time.

Firstly, general meteorological conditions are presented in Section 3.1, including the rainfall during the whole year and cropping growing season, air temperature, soil temperature and relative humidity. Section 3.2 presents the effect of different cultivation techniques on soil temperature and soil moisture. Then follow the effects of these treatments on soil bulk density (Section 3.3) and soil fertility (Section 3.4) which includes soil total and available N, P, K, organic matter, soil pH, available Mg, Cu, Fe, Zn and Ca. Crop development, yield and yield parameters are discussed in Section 3.5. The final two sections present the cost benefit analysis (Section 3.6) and the relationship between selected parameters (Section 3.7). The yields for winter wheat are presented in Section 3.8.

3.1 Meteorological Measurements

General meteorological statistics for the 1999, 2000 and 2001 cropping seasons from Kelang Meteorological Station are presented in Table 3.1.1, with the rainfall data in Figure 3.1.1. For 2001, data were also obtained from an automatic weather station established in the catchment.

3.1.1 Rainfall

Three years rainfall distribution is shown in Figure 3.1.1 and further precipitation pattern from seed sowing until harvest is given in Figure 3.1.2.

Rainfall distribution during three years of research

The rainfall distributions of the whole of 1999 and 2000 and from 01 January-07 October 2001 are shown in Figure 3.1.1. In 1999, the total rainfall was 1028.7 mm

Table 3.1.1. General climate statistics data of Kelang Meteorological Station

Year	Parameters	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1999	Total rainfall (mm)	74.7	0.0	5.7	5.0	115.6	81.1	292.5	250.3	141.0	20.4	32.9	9.5
	Mean max. air Temperature (°C)	15.5	21.1	24.3	26.6	23.1	27.3	26.5	25.9	25.1	23.5	18.4	14.2
	Mean min. air Temperature (°C)	-0.8	2.8	5.6	11.2	13.0	17.2	16.5	15.4	13.6	12.1	5.2	1.3
	Mean air Temperature (°C)	7.4	11.9	14.9	18.9	18.0	22.2	21.5	20.6	19.4	17.8	11.8	7.8
	Mean 15 cm soil Temperature (°C)	7.0	10.2	14.1	19.8	18.4	27.6	20.9	20.1	18.5	17.0	11.7	8.1
	Mean monthly relative humidity (%)	82.0	73.0	47.0	72.0	85.0	85.0	91.0	93.0	92.0	90.0	87.0	85.0
2000	Total rainfall (mm)	4.9	2.3	25.5	0.7	94.3	153.3	130.0	207.2	77.2	79.3	10.4	8.3
	Mean max. air temperature (°C)	15.8	17.2	20.8	24.3	25.2	24.3	26.0	26.0	23.9	22.6	18.3	16.4
	Mean min. air temperature (° C)	-0.5	2.6	4.4	8.9	12.9	15.9	16.1	16.2	14.4	13.0	3.6	1.3
	Mean air temperature (° C)	7.7	9.9	12.6	16.6	19.1	20.1	21.1	21.1	19.2	17.8	11.0	8.9
	Mean 15 cm soil temperature (°C)	6.0	8.2	12.0	16.7	18.9	20.1	20.7	20.4	19.1	16.8	10.6	7.7
	Mean monthly relative humidity (%)	75.0	69.0	65.0	83.0	83.0	96.0	91.0	92.0	90.0	91.0	83.0	80.0
2001	Total rainfall (mm)	1.0	18.3	9.8	0.7	153.1	226.3	154.1	186.7	97.0	14.6*		
	Mean max. air Temperature (°C)	17.8	17.3	18.8	27.0	23.1	24.1	27.7	26.5	24.5	19*		
	Mean min. air Temperature (°C)	0.8	1.8	2.9	8.9	12.3	14.3	17.5	16.7	16.3	13.9*		
	Mean air temperature (°C)	9.3	9.6	10.9	18.0	17.7	19.2	22.6	21.6	20.4	16.5*		
	Mean monthly relative humidity (%)	72.0	70.0	66.0	62.0	65.0	74.0	89.0	87.0	89.0	91.0*		
Note* the first week (01-07) October 2001													

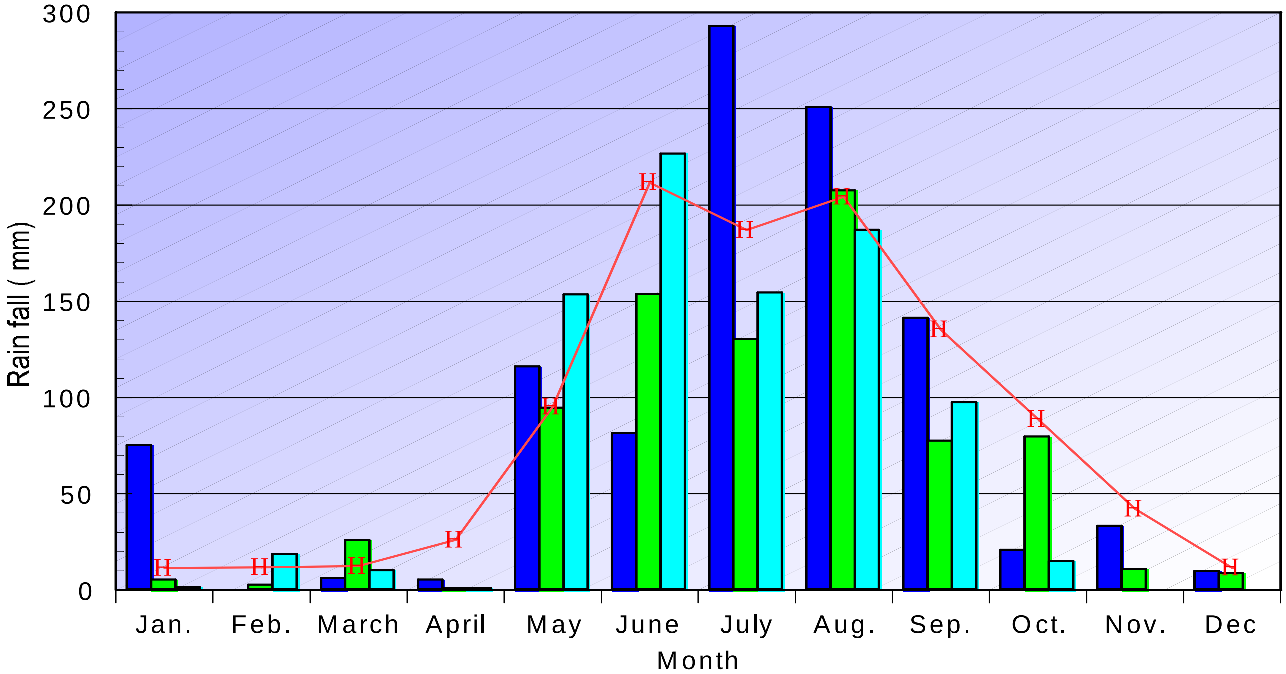


Figure 3.1.1 The monthly rainfall distribution during the three experimental years: B 1999, B 2000, B 2001 (from Jan. to Oct.7) and H 20 years' mean

and this value is close to the 20 year mean, which was 1038.1 mm (Yunnan Meteorological Station, 1980). Most rainfall was concentrated in May, July, August and September. January also had more rainfall, but in February little rain fell in all years.

Total rainfall in 2000 was 793.4 mm and this was less than the 20 years mean. More rain fell from May to October. In 2000, April was a very dry month. The rainfall in 2001 had a similar trend to 2000, the total rainfall was 847.0 mm (from 01 January to 07 October), a little more than 2000 and the driest months were January and April.

Precipitation pattern from seeds sowing until harvest

For the crop, the monthly rainfall totals and distribution during the cropping season are much more important rather than the whole year. To enable interpretation of these data, the rainfall distribution from sowing until harvest is shown in Figure. 3.1.2. From the curve patterns, the rainfall over three years research shows there was a relatively even rainfall distribution in 2000 and the cropping season rainfall occupies 82.2% of the total year's rainfall. A very changeable pattern was found in 1999 and little rain fell 40 days after seeds were sown. This stage is very crucial for crop development and growth and had implications for treatment effectiveness (Section 3.5).

In 2001, more rain fell in the crop early stage and the distribution was relatively even.

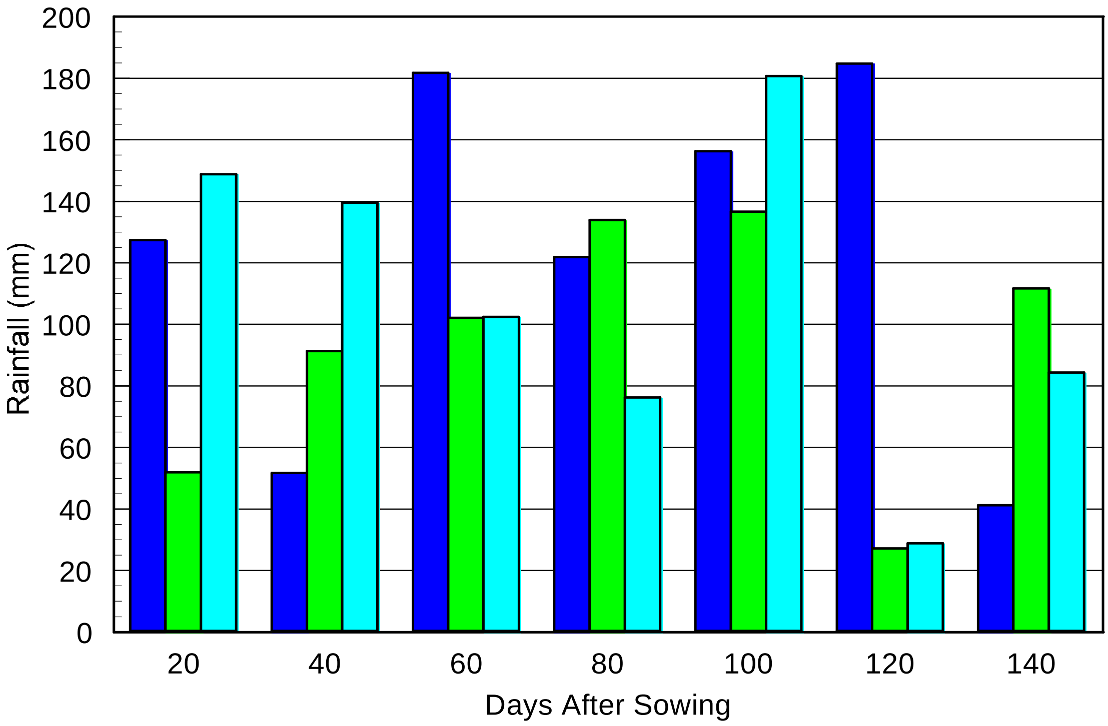


Figure 3.1.2 Rainfall distribution during the three experimental seasons. result represents accumulated rainfall between DAS B 1999 (Sowing on19/05/99 and harvesting on 07/10/99), B 2000 (Sowing on17/05/00 and harvesting on 07/10/0) and B 2001(Sowing on18/05/01and harvesting on 07/10/01)

Unfortunately, an unexpected heavy hail storm (09 August) influenced final yields considerably.

3.1.2 Air temperature and soil temperature at 15 cm depth

Air temperature is one of main factors affecting soil temperature, so this section considers these two items together (Figure 3.1.3 and Figure 3.1.4). The mean air temperature was calculated from air maximum and minimum values. During three experimental years, the extreme maximum temperature in 1999 was observed on three days (24 April, 04 May and 24 July), at 31.5°C. The extreme minimum temperature was –7.5°C, which was recorded on 25 December and in the following four days the temperatures remained <-5°C. In 2000, the extreme maximum temperature was on 28 July (32.2°C) and the extreme minimum temperature was -5°C, recorded on 01 and 06 January. In 2001, the maximum temperature was also 31.5°C, recorded on 19 June and 21 July and the extreme minimum temperature was –3.5°C, recorded on 12 January.

For the monthly mean air temperature, the pattern of three years was similar. From January to June or July or August, the temperature increased each month, then after August the temperature decreased slowly and it became progressively colder. Little difference was found between the different years. In 1999, the warmest month was June and in May the mean air temperature was lower than in April. This was probably affected by rainfall, usually little rainfall occurs in April and the rainy season started in May (see Section 3.1 rainfall). Few rainfalls in June also made the air temperatures higher, due to little cloud cover. In 2000, the air temperature curve pattern was nearly the same as the 20 year mean air temperature, just at the latter stage the temperature was higher than the 20 years mean value. In 2001, January was a relatively warm month, but February and March were a little colder compared with 1999, 2000 and the 20 year mean. The remaining months nearly followed the pattern of 1999, the warmest month in 2001 was July.

Soil temperature at 15 cm soil depth in 1999 and 2000 and the 20 year mean is shown in Figure 3.1.4. The data in 2001 were not completely recorded, because of the damaged thermometer at Kelang Weather Station, but the Delta Logger supplemented these data (Table 3.1.2). The pattern of soil temperature followed similar trends as air temperature. The soil temperature in 1999 and 2000 had a different pattern, in 1999, greater change was found in April, May and June. Both April and June had unusual higher temperature, at 19.8 and 27.6°C, respectively (Figure 3.1.4). This temperature was greater by 2.6 and 7.5°C compared with the 20 year mean. Low temperatures were found in May, the mean temperature was 18.4°C, 1.1°C less than the mean. In 2000, the soil temperature of the whole year was a little below the 20 year mean.

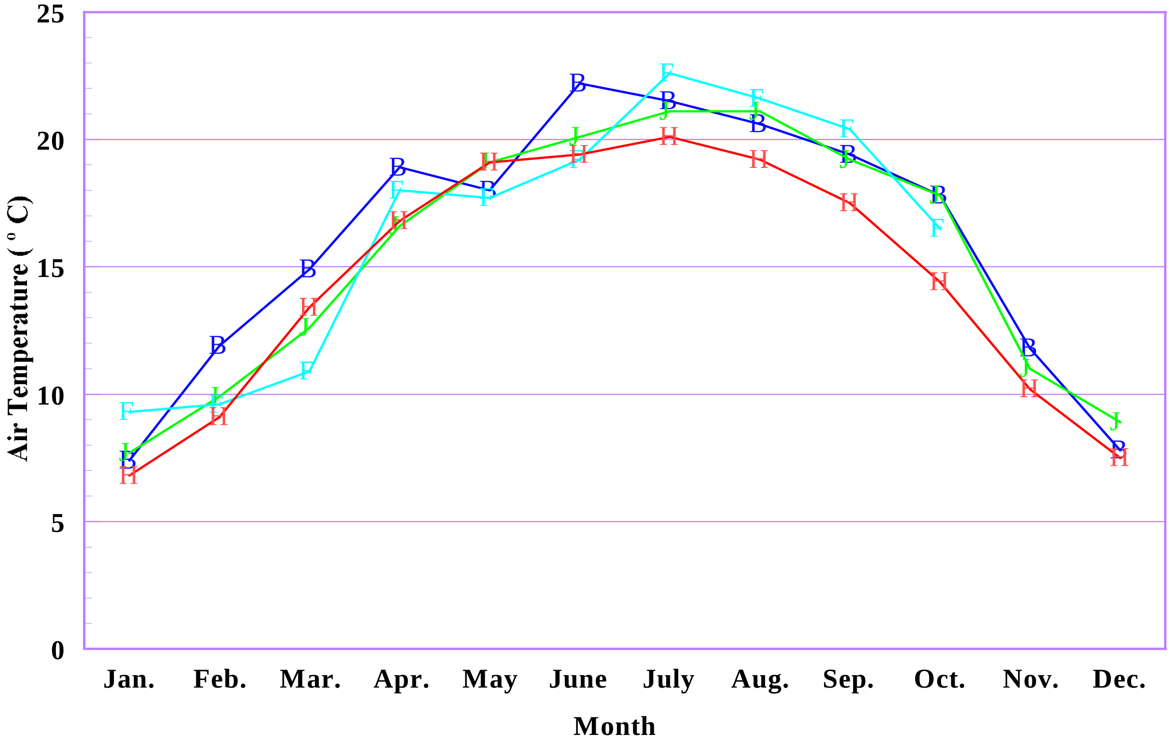


Figure 3.1.3 Mean monthly air temperature at 0900 at Kelang Weather Station: B 1999, J 2000, F 2001 and H 20 years mean (From Xing dian County Weather Station)

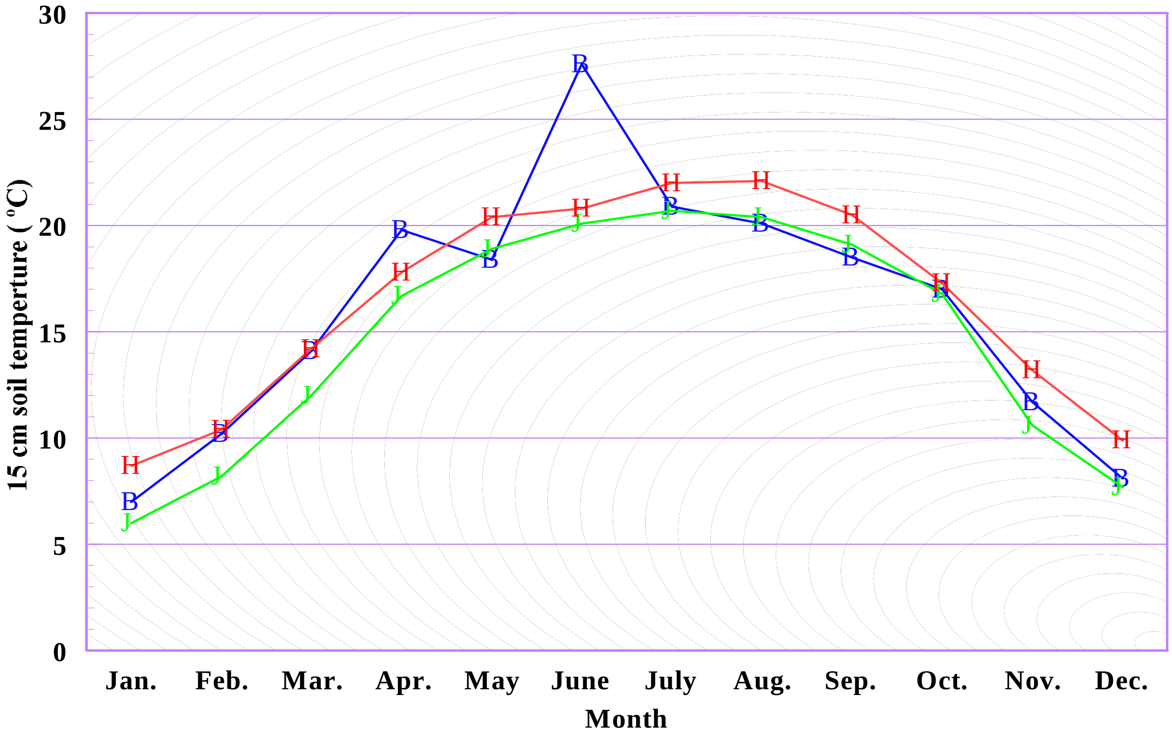


Figure 3.1.4 Soil temperature at 15 cm depth at 0900 : B 1999, J 2000 and H 20 years mean (From Xing dian County Weather Station)

3.1.3 Air Relative Humidity

Air relative humidity was calculated using a Hygrometric Ruler from the mean Dry and Wet Bulb data each month in 1999, 2000 and 2001 at Kelang Weather Station. These data were strongly influenced by rainfall and air temperature (Figure 3.1.5).

There are different curves over the three years of research. In 1999, the air relative humidity in March was very low, which was lower than the same month in 2000 and 2001. Conversely, a high relative humidity was observed in August. In 2000 and 2001, the lower air relative humidity was also observed in March, but higher air relatively humidity was recorded in June and October, respectively. Generally, the relatively humidity of 2001 was lower than the other two years.

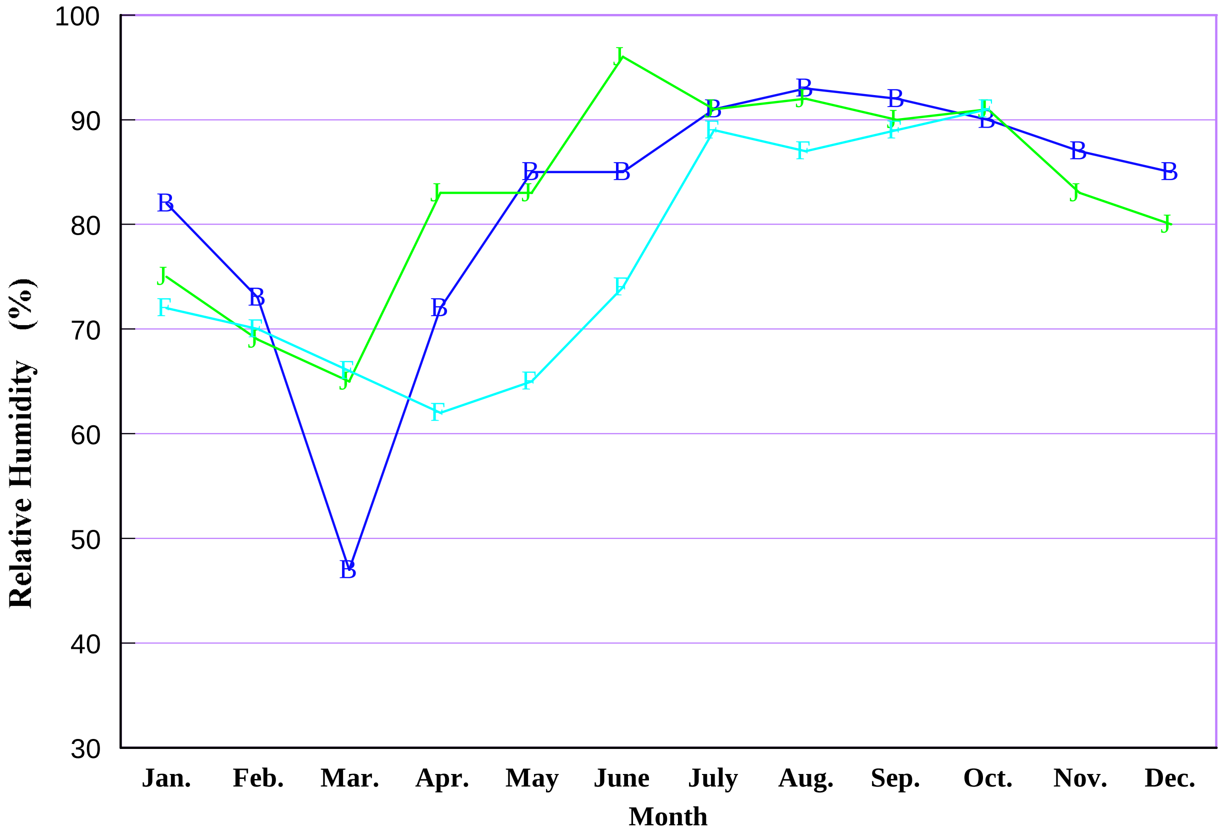


Figure 3.1.5 Mean relative humidity at 0900 at Kelang: B 1999, J 2000 and F 2001

3.1.4 General meteorological conditions recorded during the 2001 cropping season at the Delta-T Weather Station

Further meteorological data were recorded by the Delta-T Logger in the catchment in the 2001 cropping season (Table 3.1.2). Generally, during the cropping season, the wind in the catchment was between 166.2 and 173 degrees, this means the wind direction was predominantly north-westerly and the mean wind speed was 1-2.2 m s^{-1}. The mean air temperature was 15.9-20.6°C and soil temperature at 15 cm was 17.6-21.0°C for the cropping season. For solar radiation, greater values were recorded nearly in the middle of the crop growing season and lower values recorded at the later cropping stage. Occasionally, strong solar radiation also occurred in the early cropping stage.

Table 3.1.2. General meteorological conditions during the 2001 cropping season recorded using the Delta-T Logger Weather Station (19 May-07 October 2001)

DAS *	AN1 (m s^{-1})	Wind direction (degree)	Air Temperature (°C)	Relative Humidity (%)	15 cm Soil Temperature (°C)	Rainfall (mm)	Solar Radiation (w m^{-2})
10	Not recorded	Not recorded	17.7	74.0	18.8	57.9	61.1
20	1.5	172.1	16.9	84.2	17.6	38.0	63.1
30	1.6	171.5	20.6	67.4	20.3	10.2	93.2
40	1.4	168.9	20.1	78.1	20.5	54.4	67.3
50	2.2	168.6	19.4	81.2	21.0	19.0	71.9
60	1.0	166.2	19.3	82.3	21.2	20.0	94.8
70	1.1	166.0	19.4	79.7	21.4	22.0	92.8
80	1.1	163.3	19.0	81.5	20.7	25.6	83.8
90	1.0	168.3	19.1	81.5	20.1	62.8	76.8
100	1.0	173.0	19.6	85.3	21.0	22.2	56.9
110	1.3	170.5	19.0	77.9	19.9	0.0	54.7
120	1.1	168.5	18.8	78.1	19.6	14.2	52.7
130	1.0	170.1	17.8	82.8	19.7	29.8	66.7
140	1.1	167.8	15.9	82.6	18.7	7.8	40.8

DAS = Days After Sowing.

3.2 Soil temperature and soil moisture

For soil temperature, the measurement methods of 1999, 2000 and 2001 were different. In 1999 soil temperature was recorded at 20 day intervals at four soil depths and each day recorded three times, at 0700-0800, 1400-1500 and 1700-1800. After two measurements for all plots, the remaining measurements were just in Block A, which kept the relatively consistent measurement time. The total measurement times were six in 1999. In both 2000 and 2001, soil temperature was taken at random intervals at the soil surface and 5 cm depth. Soil moisture was measured the same way. In 1999 gravimetric soil moisture was taken at 20 day intervals at three soil depths (5, 10 and 15 cm). In both 2000 and 2001 volumetric soil moisture was taken on randomly selected days at 6 cm soil depth. The following sections present and discuss the soil temperature and moisture data separately. First is soil temperature in different years, and then soil moisture in different years and using different measurements.

3.2.1 Soil temperature

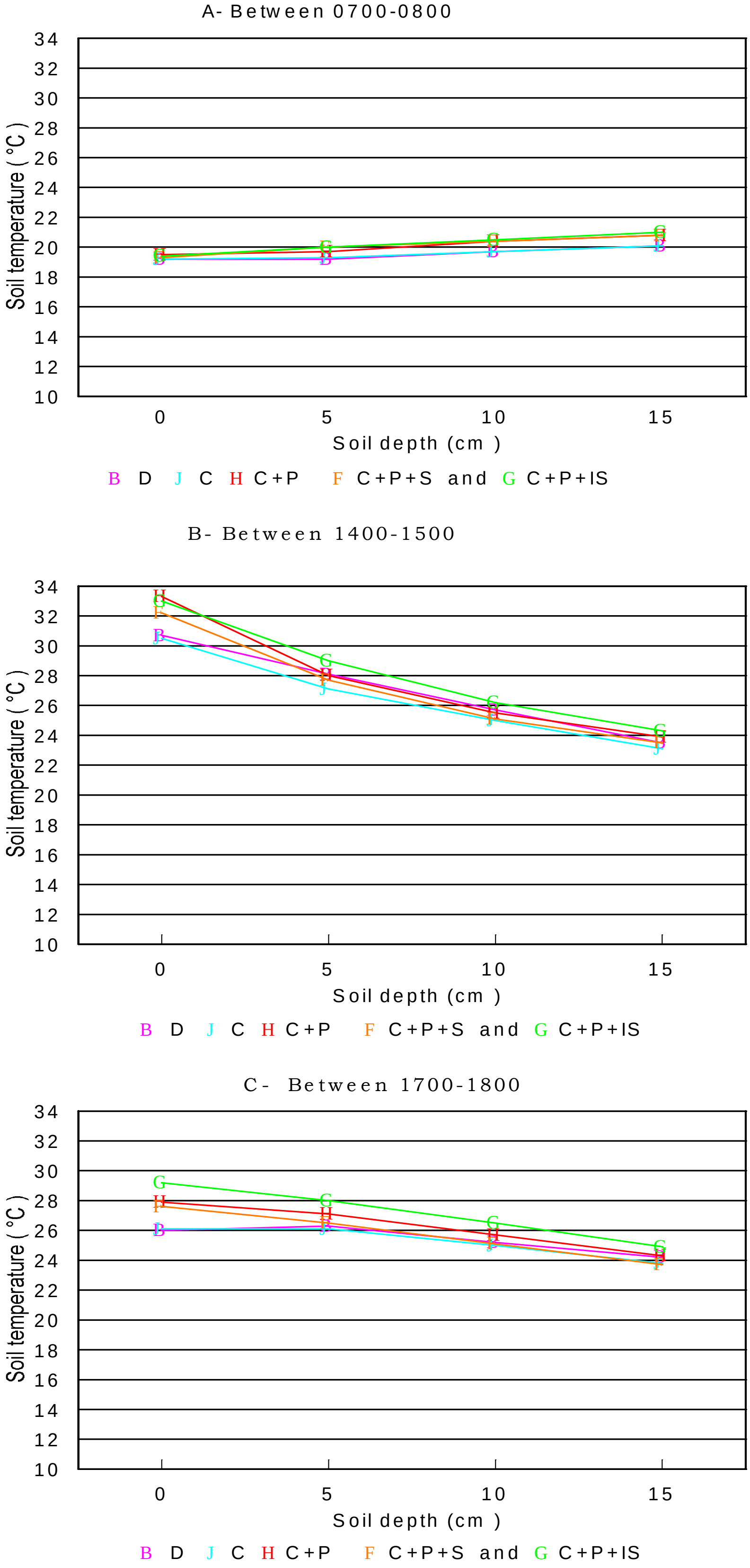
3.2.1a Soil temperature in 1999

Soil temperature in 1999 was recorded at four soil depths and was measured on six occasions. Figure 3.2.1 shows the mean soil temperature changes at the four soil depths over the whole cropping season. Individual measurements are given in Figures 3.2.2-3.1.5.

The highest soil temperature was observed on the C+P+IS treatment during the whole cropping season, with C+P treatment ranked second (Figure 3.2.1). The lowest soil temperature was on the D and C treatments, while C+P+S treatment was in the middle. The largest difference between treatments occurred in the later day (between 1400-1500 and 1700-1800) and in the upper soils, especially at the soil surface.

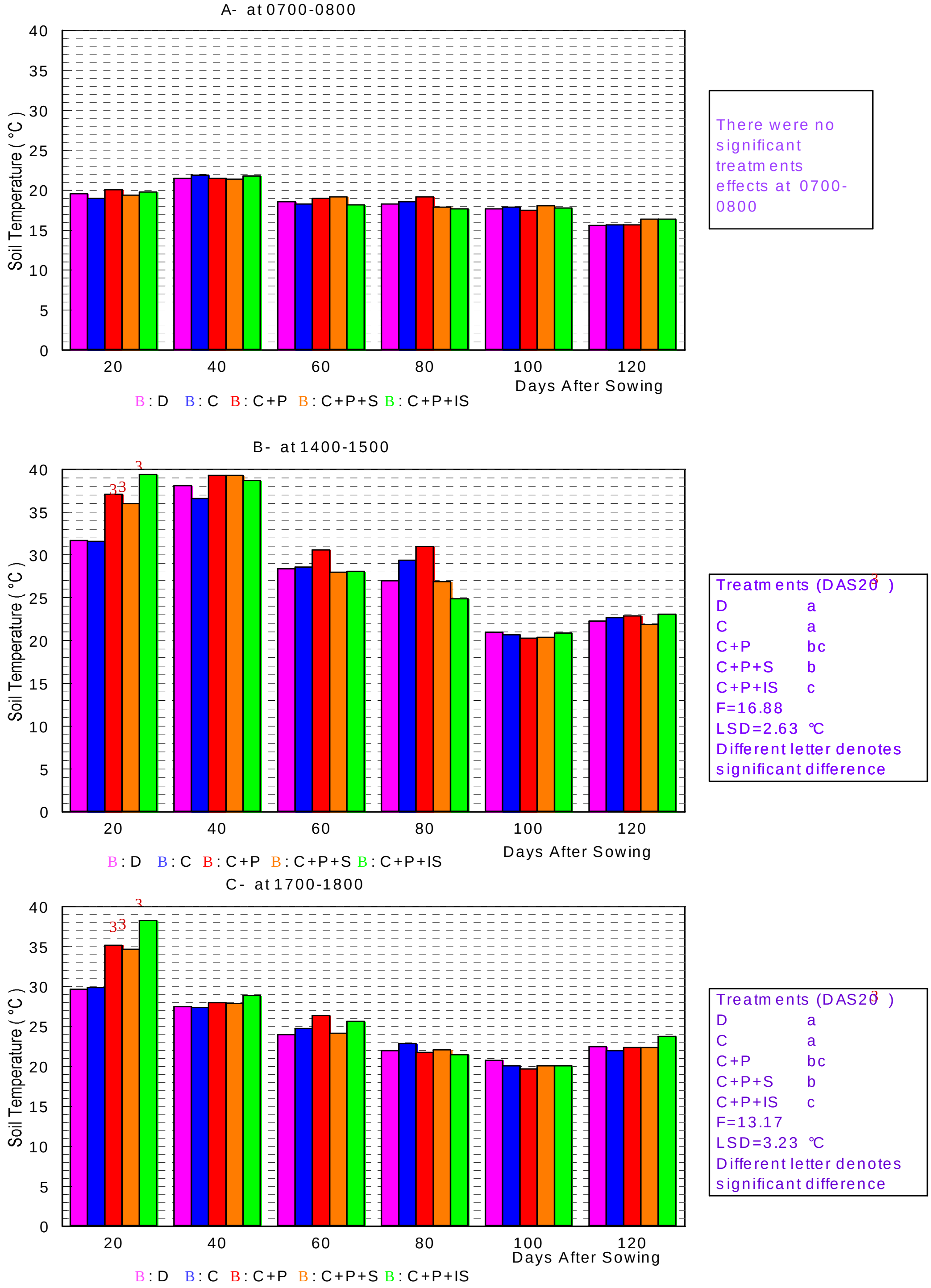
Figure 3.2.1 also shows that soil temperature under all treatments increased with the increasing soil depth at 0700-0800, thus 15 cm >0 cm >5 cm >soil surface. Conversely, between 1400-1500 and 1700-1800, soil temperature decreased with soil depth, especially for soil temperature between 1400-1500. This is easily understood by solar radiation and soil is also a heat conductor. During the day the strong solar radiation directly heated the soil and the soil absorbed some solar energy, which led to warming. On the contrary, during the night, soil disperses heat back to the air, which then leads to it becoming colder.

Figure 3.2.1. Mean soil temperature at different soil depths at 0700-0800, 1400-1500 and 1700-1800 under different cultivation techniques during the cropping season in 1999



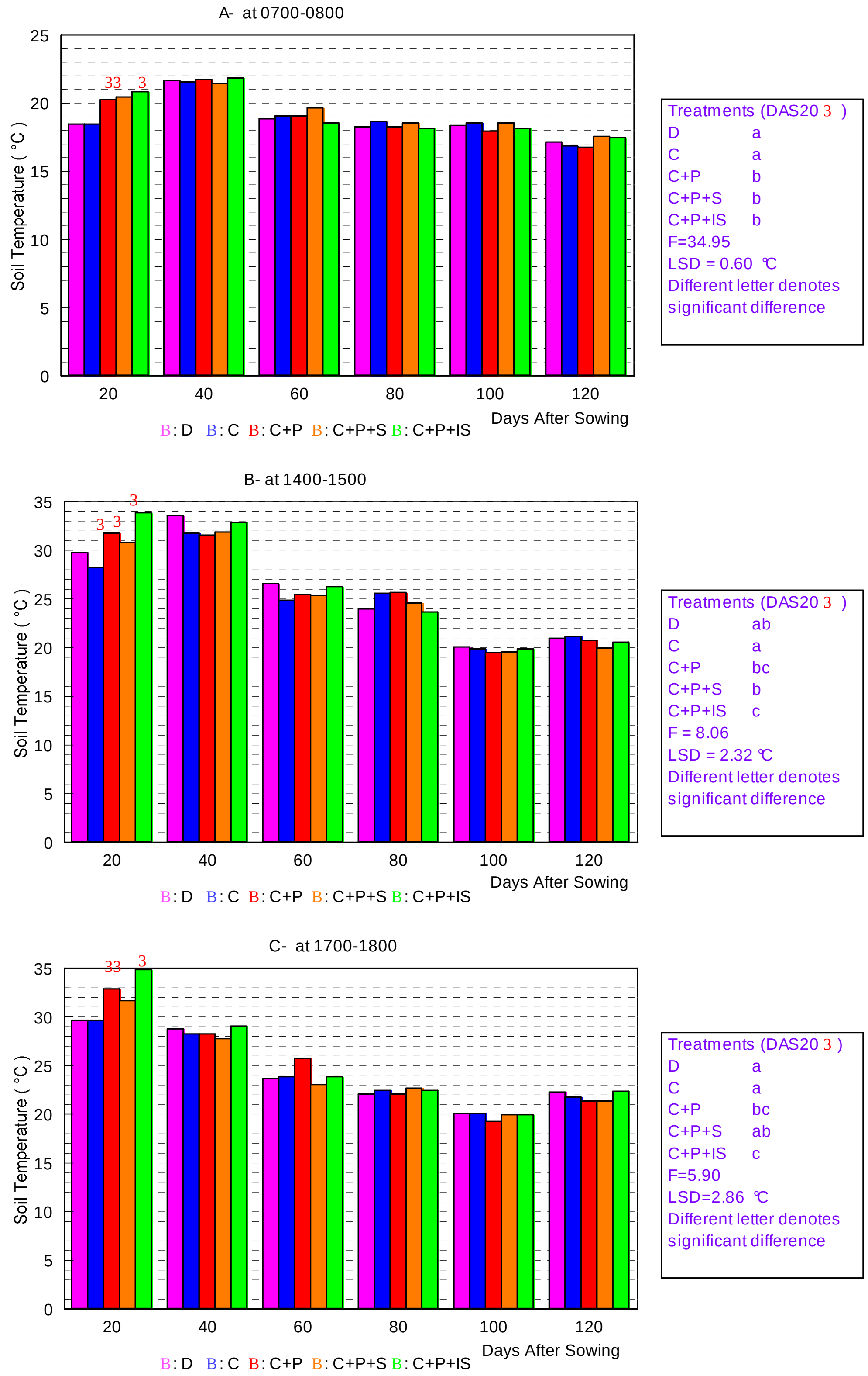
For the individual measurements, there were no significant treatment effects for the soil surface between 0700-0800, but significant treatment effects were found on one out of six times between 1400-1500 and 1700-1800, which occurred 20 days after sowing (Figure 3.2.2). On this occasion, C+P+IS, C+P and C+P+S had a significantly higher soil temperature than D and C treatments, while C+P+IS had the highest soil temperature.

Figure 3.2.2 Soil surface temperature daily changes under different cultivation techniques during 1999 cropping season



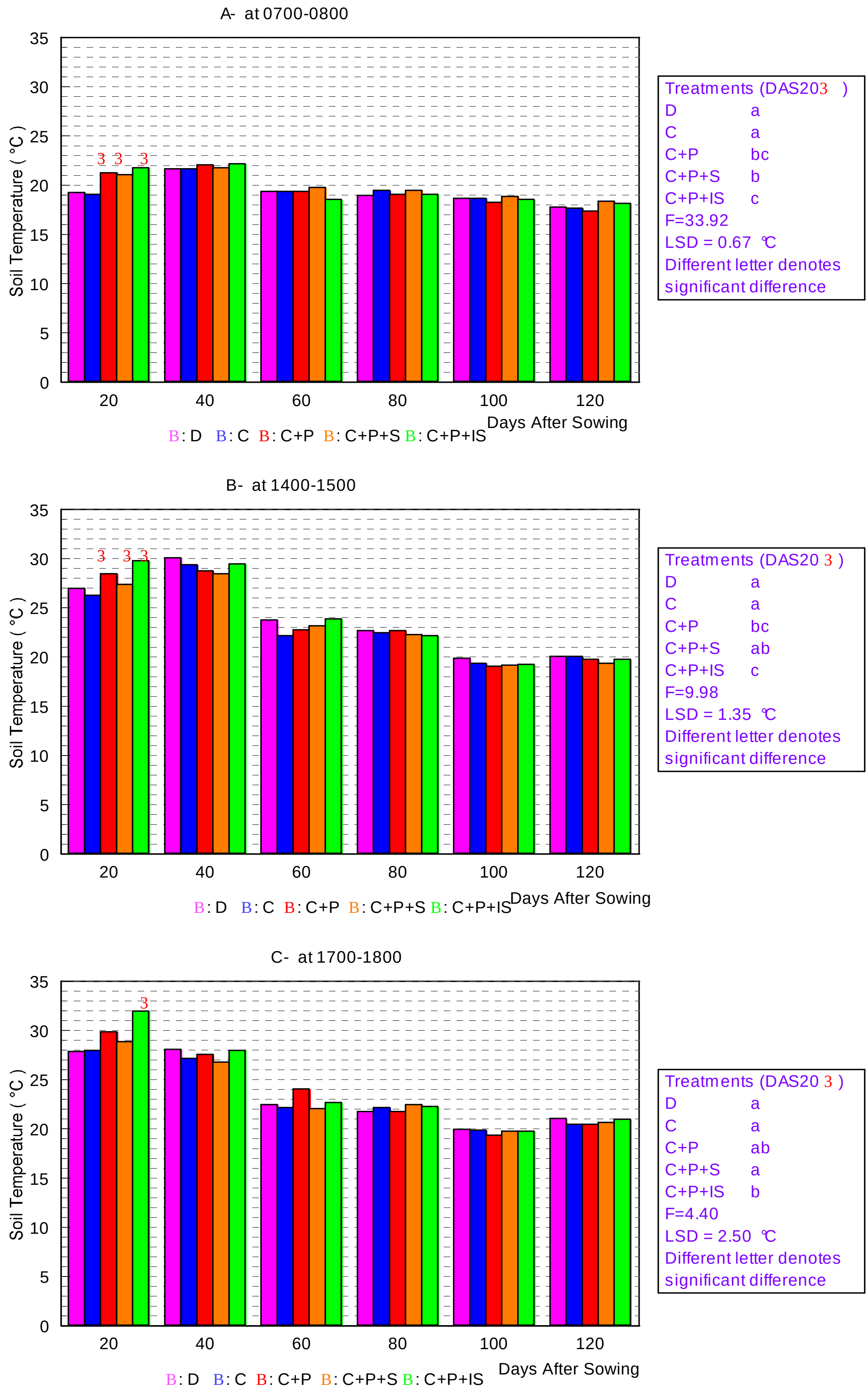
For the 5 cm soil depth, significant treatment effects were found between 0700-0800, 1400-1500 and 1700-1800 on 20 DAS (Figure 3.2.3). On this occasion, C+P+IS and C+P had a significantly higher soil temperature than D and C treatments. C+P+S was between them and C+P+IS always had the highest soil temperature.

Figure 3.2.3 Soil temperature daily changes at 5 cm depth under different cultivation techniques during the 1999 cropping season



For the 10 cm soil depth, the same trend was found as at 5 cm, but between 1700-1800, just C+P+IS had a significant difference with other treatments (Figure 3.2.4).

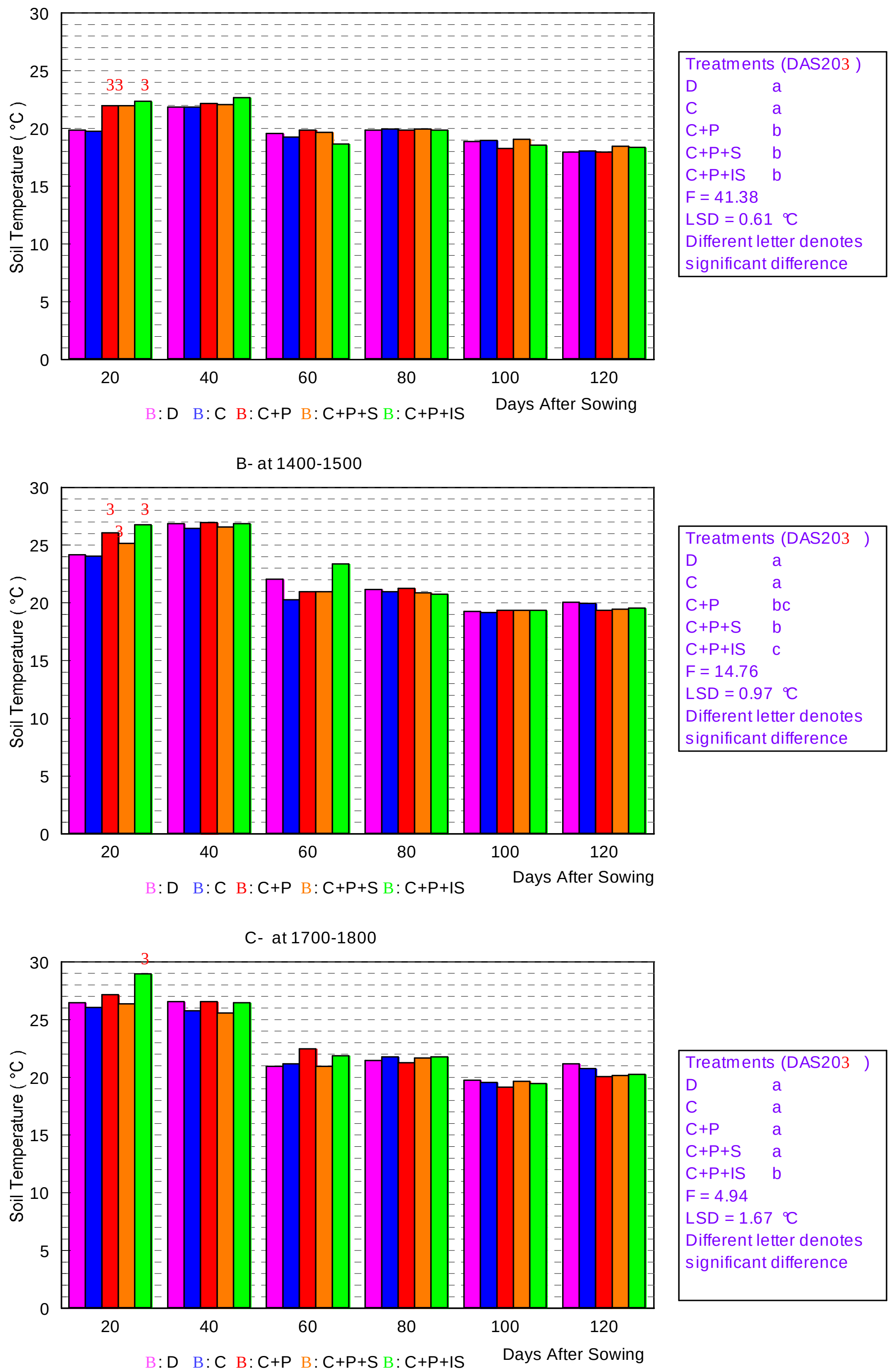
Figure 3.2.4 Soil temperature daily changes at 10 cm depth under different cultivation techniques during the 1999 cropping season



Soil temperature at 15 cm soil depth had the same trend as at 10 cm, in which C+P+IS had the highest soil temperature, C+P was second, then C+P+S. The lowest soil temperatures were observed on D and C treatments (Figure 3.2.5).

Figure 3.2.5 Soil temperature daily changes at 15 cm depth under different cultivation techniques during the 1999 cropping season

A- at 0700-0800



For all treatments, there was no significant difference between treatments at the late cropping season, probably due to the soil being shaded later in the season by the canopy which reduces the variation in temperature at the soil surface. In particular, the glasshouse effect of the polythene mulch is substantially reduced in diffuse sunlight compared to high levels of direct short-wave radiation.

3.2.1b 2000 and 2001 Soil temperature

Soil temperature was measured on all the blocks at two depths 1 and 5 cm during the 2000 and 2001 seasons. On each measurement, the temperature readings were taken at 1100-1200, with 10 replicates for 2000 and five replicates for 2001 (some instruments were damaged) on each plot. Under C+P+S treatment, besides taking soil temperatures under polythene mulch, soil temperature under straw mulch was also taken concurrently with other treatments. Figures 3.2.6a and 3.2.6b show the soil temperature at 1 and 5cm depths, respectively.

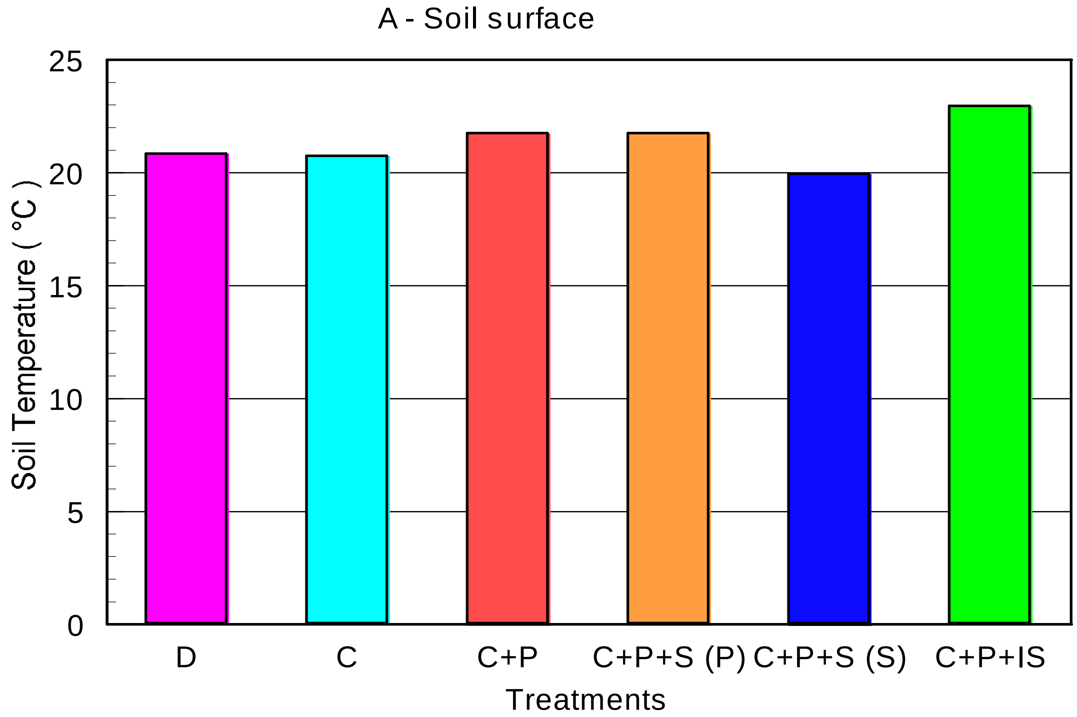
Soil temperatures at the soil surface during the 2000 and 2001 cropping season are shown in Figure 3.2.6a. In 2000 (Figure 3.2.6a-A), the highest soil temperature was observed on C+P+IS (22.9°C), while the lowest soil temperature was on C+P+S (S) (19.9°C), the difference being +3.0°C. C+P and C+P+S (P) also had high soil temperature, followed by D (20.8°C) and C (20.7°C) treatments, the difference between them was ~1°C.

Soil temperature in 2001 had the same trends as 2000. Treatment rank was C+P+IS >C+P+S (P), C+P >C, D >C+P+S (S). The highest temperature under C+P+IS was 25.0°C, while the lowest temperature under C+P+S (S) was 20.9°C, a difference of +4.1°C. This proved that the polythene mulch treatments increase soil temperatures, while straw mulch had the opposite effect.

The curve of soil temperature at 5 cm soil depth (Figure 3.2.6a-B and 3.2.6b-B) was smoother than the curve at 1 cm depth. This means the soil temperature at 5 cm depth had relatively small change compared with the soil temperature at 1 cm depth, but the trends were similar. In 2000, the difference between highest soil temperature under

C+P+IS and lowest soil temperature under S+P+S (S) was 2.7°C; in 2001, the difference between them was 2.2°C.

Figure 3.2.6a Mean Soil temperature at surface (A) and 5cm depth (B) during the 2000 cropping season (n = 9)



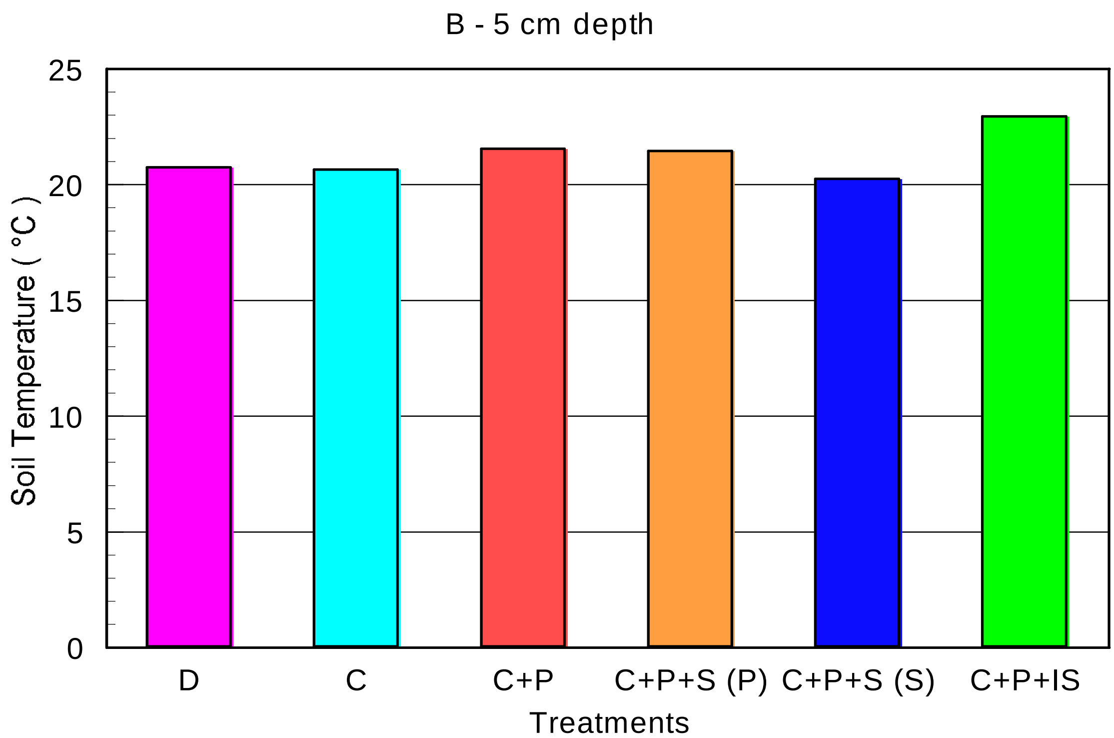
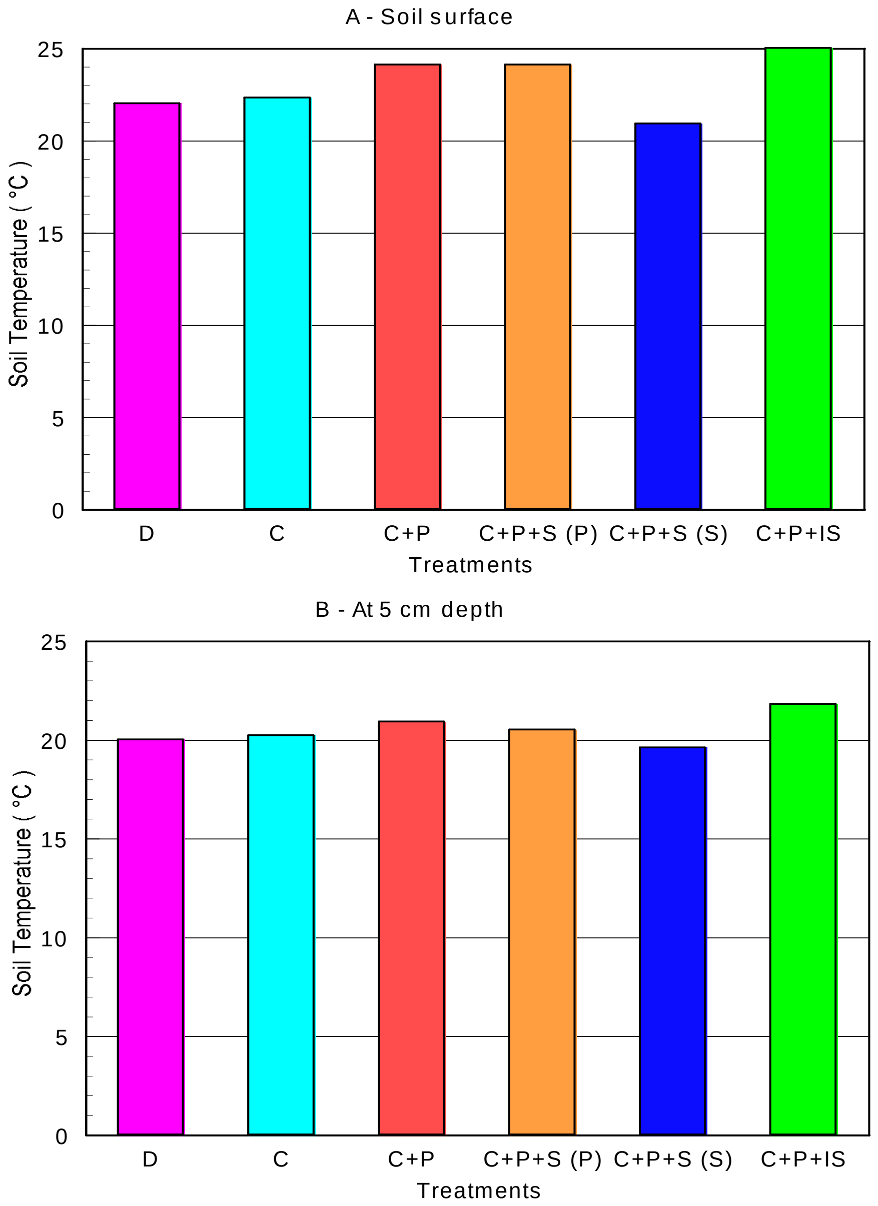


Figure 3.2.6b Mean soil temperature at soil surface (A) and at 5 cm depth (B) during the 2001 cropping seasons (n = 10)



Individual measurements

Seasonal average values during the 2000 and 2001 cropping seasons are given on Figure 3.2.6 a,b. The individual measurements are also presented on Table 3.2.1-2 along with associated F, P and LSD values. For soil surface temperature in 2000 (Table 3.2.1), significant treatments differences were observed on four occasions out of nine measurements, these being 23, 30, 43 and 112 DAS. These all occurred at a very early stage, just one exception at the later stage. On these occasions, C+P+IS had the highest soil temperature, while C+P+S (S) had the lowest soil temperature, the greatest difference between them was 13.6°C which occurred on 30DAS. C+P and C+P+S (P) also had higher soil temperatures than D and C, the greatest difference between them was 3.4-5.9°C.

Table 3.2.1. Soil temperature (℃) at soil surface and 5 cm depth with F, P and LSD over the 2000 cropping season. Value is the mean of 10 replicate measurements on each plot.

Soil depth (cm)	DAS	F	P	LSD (℃)	D	C	C+P	C+P+S(P)	C+P+S(S)	C+P+IS
Soil surface	23	19.724	<0.001	0.91	18.8a	18.5a	20.4b	20.5b	18.4a	21.5c
	30	31.528	<0.001	2.67	24.8b	23.5ab	29.4c	28.2c	20.9a	34.5d
	43	8.891	<0.001	1.05	22.1ab	21.6a	23.1b	23.2b	21.4a	24.0b
	56	2.578	0.083	-	18.4	18.5	19.1	19.1	18.7	19.3
	69	1.912	0.166	-	21.6	22.1	21.5	22.1	20.8	21.9
	82	0.529	0.750	-	20.8	21.3	21.2	20.6	20.1	21.5
	97	1.102	0.409	-	23.2	23.2	23.3	23.5	22.4	23.5
	112	4.606	0.014	0.88	19.8a	20.2a	20.3a	20.8ab	19.9a	21.5b
	127	1.508	0.259	-	17.7	17.6	17.1	17.3	16.6	18.3
5 cm depth										
	9	4.812	0.012	1.51	21.6ab	21.3ab	22.9bc	22.7 bc	20.8a	23.6c
	23	36.12	<0.001	0.59	19.1a	19.2a	20.7b	20.4b	18.8a	20.0c
	30	24.696	<0.001	2.37	21.5bc	20.3ab	23.0c	23.3c	18.8a	29.7d
	43	13.432	<0.001	0.83	21.9a	21.6a	22.9b	2.9b	21.5a	24.1c
	56	3.973	0.023	0.71	18.5a	18.7a	19.0a	19.1ab	19.1ab	19.8b
	69	1.759	0.196	-	21.1	21.4	21.0	21.1	20.5	21.5
	82	1.168	0.379	-	20.7	20.6	21.0	20.3	20.2	21.3
	97	2.392	0.100	-	22.4	22.4	22.4	22.7	21.9	23.0
	112	0.4829	0.012	0.99	19.6a	19.9a	20.0a	20.4a	19.7a	21.5b
	127	2.234	0.118	-	16.4	16.2	16.3	16.5	16.3	17.4

At 5 cm soil depth in 2000 (Table 3.2.1), there were significant treatments effects, on six occasions out of 10 measurements. These occurred on 9, 23, 30, 43, 56 and 112 DAS. The effects of treatments were similar to soil surface temperature.

In 2001, the soil surface temperature data showed that seven occasions out of 10 had significant treatment effects, of which four occurred at an early stage and three at a later stage (Table 3.2.2). Usually, C+P+IS lead to highest soil temperature, then followed by C+P and C+P+S (P), then C and D; the lowest soil temperature was on C+P+S (S).

Table 3.2.2. Soil temperature (℃) at soil surface and 5 cm depth with F, P and LSD over the 2001 cropping season. Value is the mean of five replicate measurements on each plot. Different letter denotes a significant difference

Soil depth (cm)	DAS	F	P	LSD (℃)	D	C	C+P	C+P+S(P)	C+P+S(S)	C+P+IS
Soil surface	10	13.848	<0.001	1.82	18.5ab	18.3ab	21.4cd	20.1bc	16.7a	22.6d
	20	4.592	0.014	2.83	21.0ab	22.0abc	23.6bc	23.6bc	19.6a	25.0c
	27	66.863	<0.001	2.89	29.3a	28.9a	41.4b	41.8b	27.7a	44.3b
	37	1.984	0.153	-	24.3	24.8	27.0	26.4	23.0	28.7
	52	3.842	0.026	0.96	22.6b	22.5b	22.7b	22.4b	21.2a	22.9b
	67	1.074	0.422	-	23.0	23.2	22.8	22.8	21.9	23.1
	82	4.649	0.014	0.84	21.7a	22.9b	21.5a	22.1ab	21.6a	22.6b
	97	4.767	0.012	0.73	19.7ab	19.9abc	20.6c	20.5c	19.4a	20.4bc
	112	0.813	0.563	-	18.0	18.2	18.1	18.2	18.1	18.3
	127	9.867	<0.001	1.02	22.0b	22.4bc	22.4bc	23.4c	20.2a	22.3b
5cm depth										
	10	7.66	0.002	1.87	17.6ab	17.8ab	19.6b	19.2b	16.9a	21.5c
	20	14.338	<0.001	0.67	18.7a	18.9ab	19.5b	19.6b	18.5a	20.8c
	27	31.264	<0.001	1.85	22.3a	22.6a	27.8b	26.1b	22.4a	30.3c
	37	7.449	0.002	0.98	21.1a	21.3a	22.0a	21.7a	20.9a	23.3b
	52	.843	0.545	-	20.5	21.0	20.6	20.3	20.1	20.9
	67	1.146	0.389	-	21.3	21.5	21.1	20.9	20.7	21.3
	82	2.84	0.064	-	19.8	20.3	19.6	19.7	19.8	20.1
	97	16.725	<0.001	0.27	19.2a	19.4a	19.8b	19.2a	19.1a	20.0b
	112	.192	0.96	-	18.2	18.2	18.1	18.1	18.2	18.2
	127	5.939	0.005	0.98	21.6c	21.4c	20.7bc	20.2ab	19.7a	21.4c

At 5 cm soil depth (Table 3.2.2), six occasions out of 10 had significant treatment effects, of which four occurred at an early stage, and two at a later stage.

Soil temperature in 2001 was also monitored continuously using the Delta-T Logger. The reading recorded every hour. Only 12 sensors were available for connecting to the data-logger and these were installed on the following treatments (Table 3.2.3). This installation enabled the main treatments to be compared at 5 cm depth.

Table 3.2.3. The distribution of soil temperature sensors connected with the Delta-T Logger during the 2001 cropping season

Treatments: D: one sensor at 5 cm soil depth. C: three sensors at 5 cm soil depth. C+P: three sensors at 5 cm soil depth. C+P+S: three sensors at 1, 5 and 10 cm soil depths under polythene mulch; two at 1 and 5 cm soil depths under straw mulch.

The records started from the second day after sowing until harvest. Unfortunately, the data at 9-10 DAS and 82-92 DAS were corrupted. For C+P+S (S) 1 cm, the data were totally lost at the later stage because of irreparable sensor damage, but the trends of treatments were still very clear. Figure 3.2.7 shows the mean soil temperature changes over the season. Figure 3.2.8 A-C shows the daily mean soil temperature change at different times of day over a range of DAS. Figure 3.2.9 shows soil temperature under straw and polythene mulch at different soil depths.

Measurements under the polythene in treatments C+P and C+P+S (P) showed higher soil temperatures compared to downslope with difference up to 4^{o}C, especially in the afternoon in the early crop stage (about 40 DAS) (Figures 3.2.7 and 3.2.8). C+P+S (S), D and C had relatively similar temperatures. However, at later cropping stages, the difference between all treatments were small, although temperatures under the straw in C+P+S tended to be lower than all other measurements.

Daily (morning, afternoon and evening) soil temperature changes were marked (Figure 3.2.8). Soil temperature during the evening on all treatments had quite similar curves. Soil temperatures in the afternoon and early evening were higher for all treatments, with C+P+S (P) showing the greatest differential, but these time effects decreased at later crop stages.

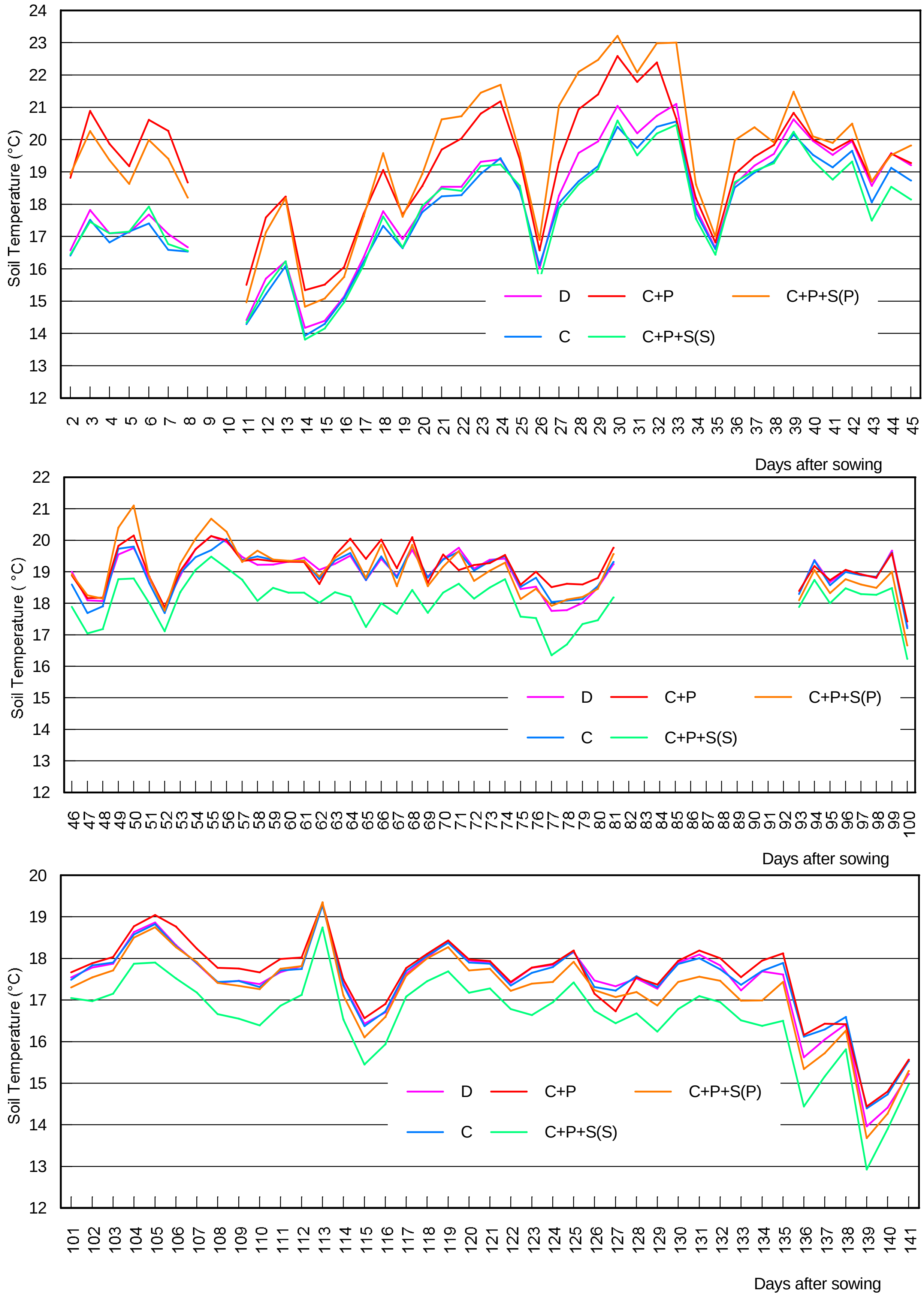


Figure 3.2.7. Soil temperature daily change under different cultivation techniques at 5 cm soil depth during the 2001 cropping season, recorded by the Delta-T Logger. The data are the mean of 24 values, recorded at hourly intervals over each day.

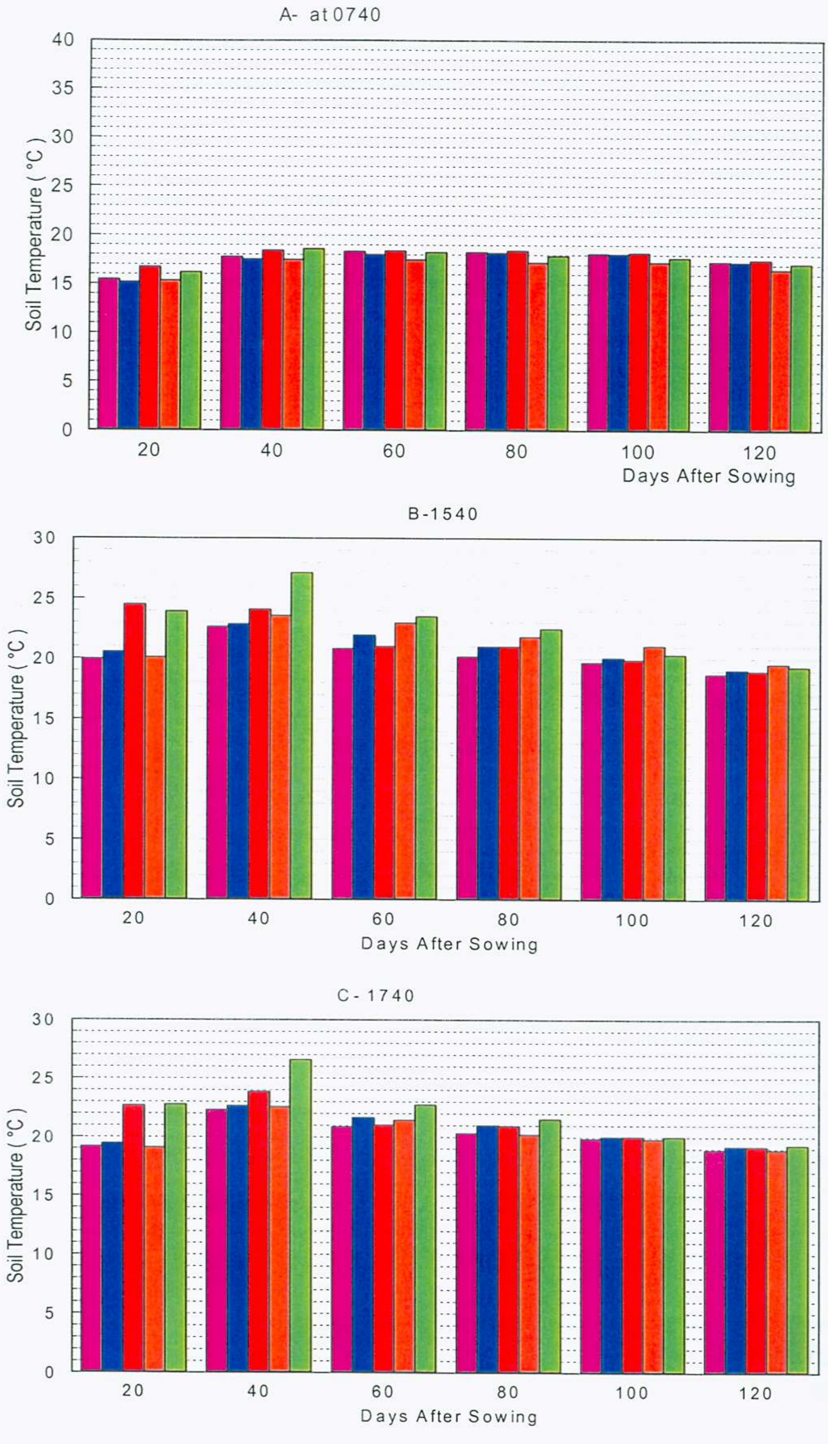


Figure 3.2.8 Mean soil temperature at selected times under different cultivation techniques ■: D ■: C ■: C+P ■: C+P+S (S) and ■: C+P+S (P) at 5 cm soil depth during the 2001 cropping season recorded by Delta-T Logger. A-at 0740, B-at 1540 and C-at 1740 (n=20)

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It confirmed that temperatures under polythene in C+P+S were consistently higher than under the straw in the same treatment, at both measured depths (Figure 3.2.9).

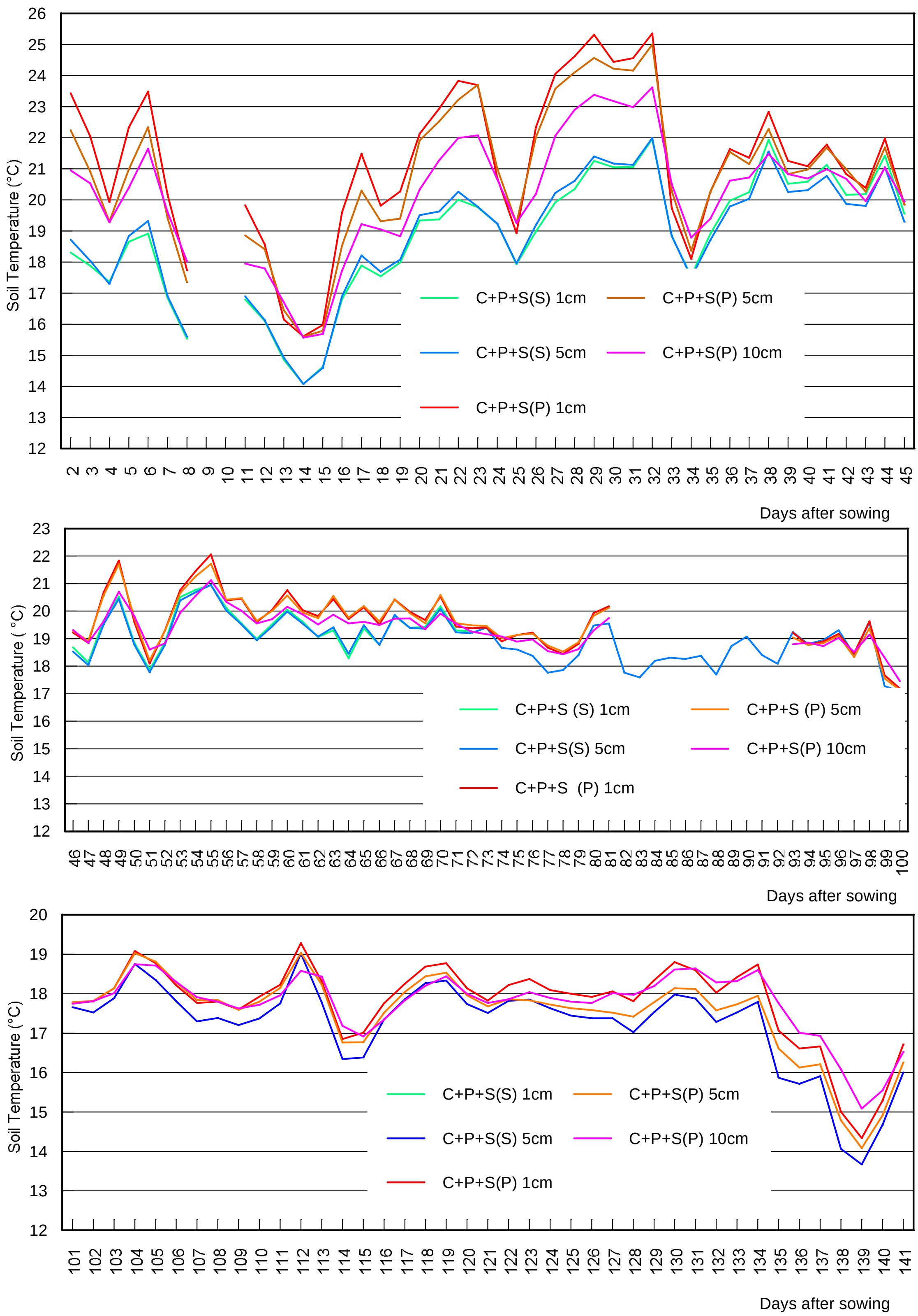


Figure 3.2.9. Soil temperature under straw and polythene mulch of C+P+S treatment at different soil depths. The data are the mean of 24 values, recorded by the Delta-T Logger.

3.2.2 Soil moisture

3.2.2a 1999 Gravimetric soil moisture

Figure 3.2.10 shows soil moisture values under different cultivation techniques at three soil depths, this value being the mean of all measurements over the season. The curves under different treatments were quite similar in 1999; the value was between 22-24% for all the treatments. Although the difference was small between treatments, C+P+S had the highest soil moisture compared with other treatments. This probably explains that on the one hand, straw mulch between the rows retains more rainfall that led to more soil moisture in the plot. On the other hand, polythene mulch had a high soil moisture during dry weather condition, hence this double function ensured that whatever the weather situation, C+P+S always had the highest soil moisture content. For other treatments, soil moisture strongly depended on weather, if there was no irrigation. If it was raining, the treatments without polythene mulch absorbed more rainfall and then had high soil moisture contents. Treatments with polythene mulch prevented more rainfall infiltrating into the soil, which led to low soil moisture contents. Conversely, during dry weather, polythene mulch treatments prevented more evaporation so keeping relatively high soil moisture. Treatments without polythene mulch had more active evaporation, so lower soil moisture values were observed.

For the individual measurement at 5 cm soil depth, significant treatment effects were found on one occasion out of six measurements (Figure 3.2.11). On this occasion (40 DAS; C+P, C+P+S (P) had higher soil moisture, whilst D and C had less moisture (F = 11.55, LSD = 2.24%). There were no significant differences at both 10 and 15 cm depths. Generally, the greatest variation was at 5 cm and least at 15 cm.

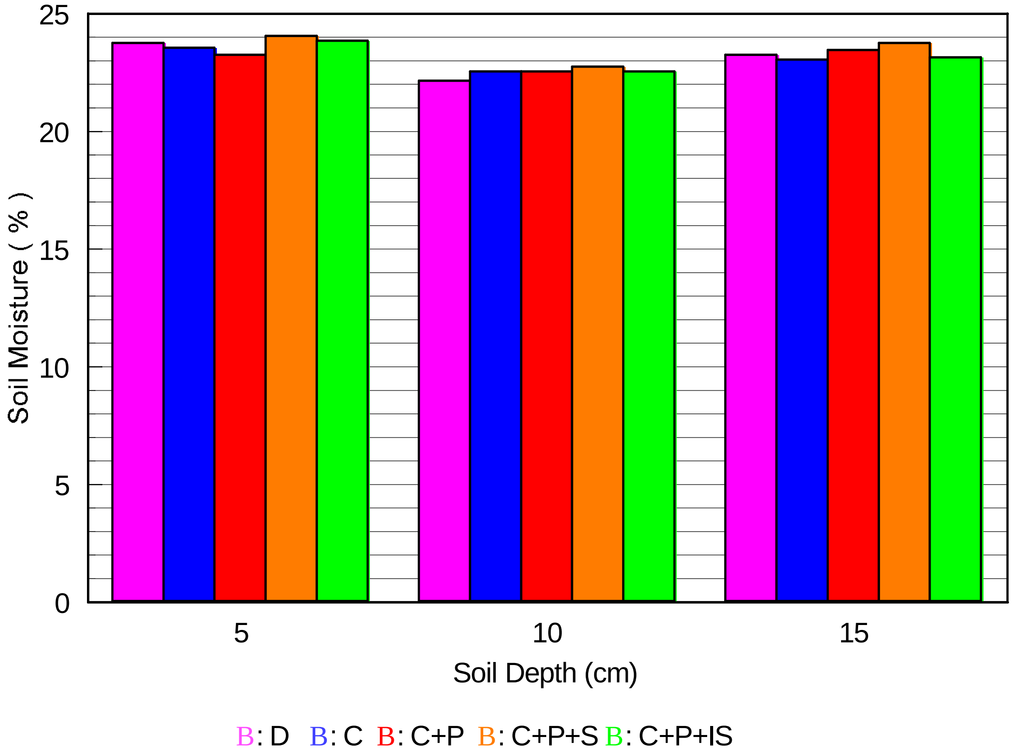
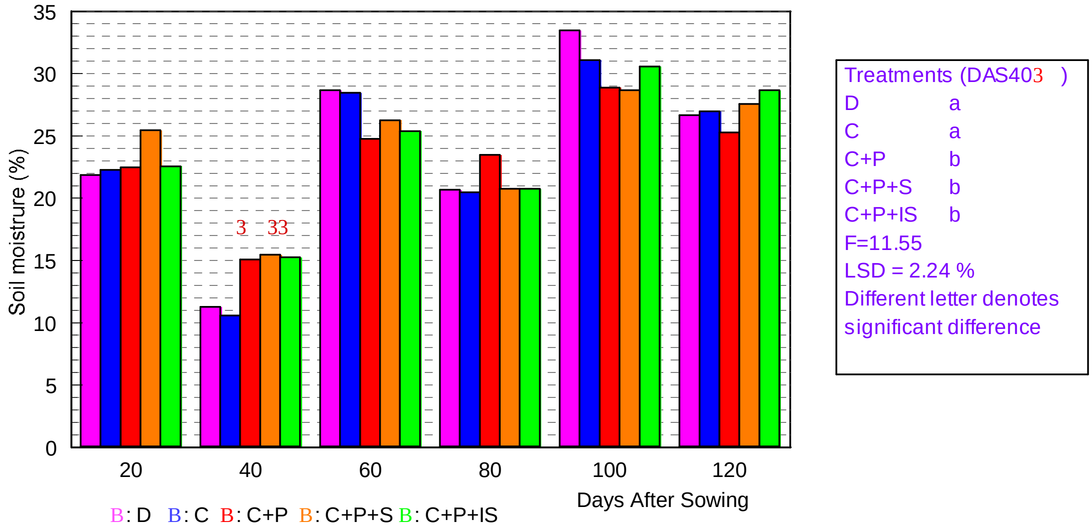


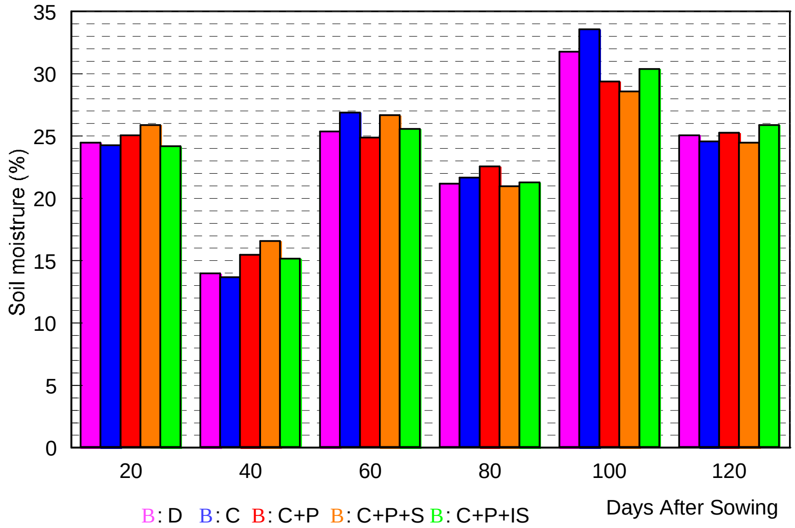
Figure 3.2.10. Mean soil moisture at three soil depth under different cultivaton techniques in 1999 (n = 6).

Figure 3.2.11 Soil moisture at three soil depths under different treatments during the 1999 cropping season (n = 3)

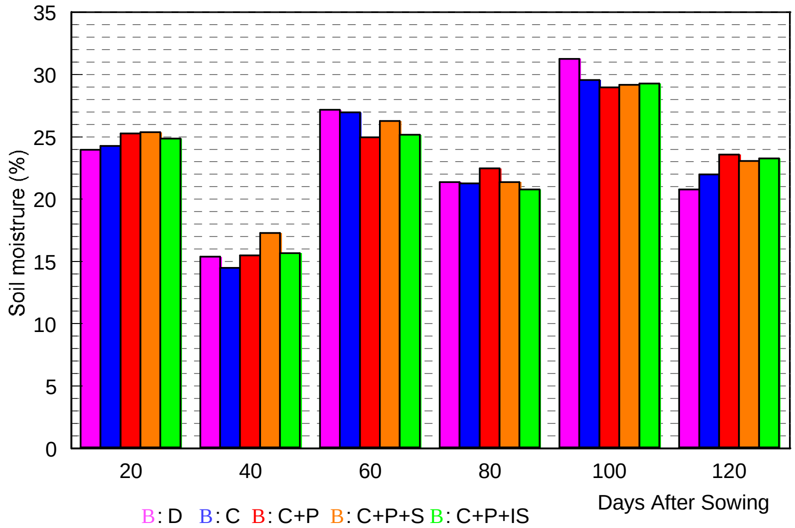
A- at 5cm soil depth



A- at 10 cm soil depth



A- at 15 cm soil depth



3.2.2b 2000 and 2001 volumetric soil moisture

Soil moisture was taken on all plots at 6 cm depth, at random intervals. The parameters were recorded five times during both 2000 and 2001. Figures 3.2.12 and 3.2.13 show 2000 and 2001 mean seasonal soil moisture under six treatments (including under straw mulch), respectively. The curves in both years did show that straw mulch retained the highest soil moisture during both seasons, followed by D and C. C+P, C+P+S (P) and C+P+IS had low soil moisture in both years.

In 2000, there were significant soil moisture differences between treatments (Table 3.2.4). Straw mulch C+P+S (S) had higher soil moisture. On seven occasions out of 10 measurements soil moisture under D and C was higher than soil moisture under C+P, C+P+S (P) and C+P+IS which were all covered by polythene mulch. This suggested that polythene mulch hindered rainfall directly infiltrating into the soil during this zero water stress year (cf. Section 3.1.1 reported that the rainfall distribution was relatively even for the 2000 cropping season). A similar situation was found in 2001.

In 2001, significant treatment effects were found on seven occasions of nine measurements (Table 3.2.5). C+P+S (S) still had higher soil moisture, then D and C. The lowest soil moisture also recorded under C+P, C+P+S (P) and C+P+IS.

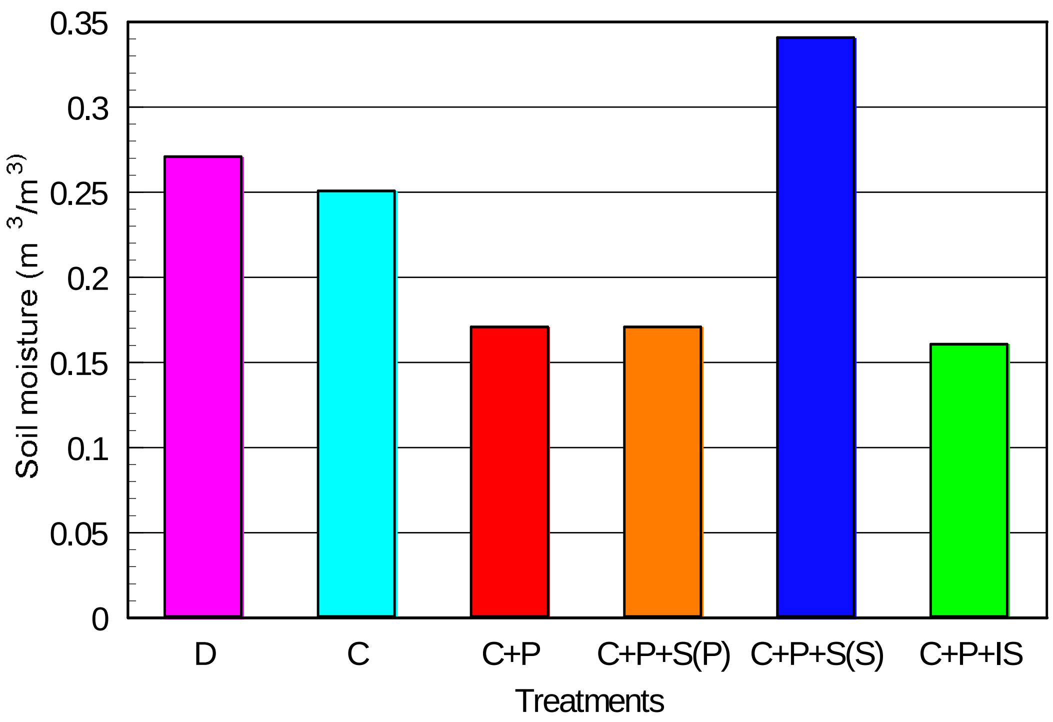


Figure 3. 2.12 Soil moisture under different cultivation techniques in 2000

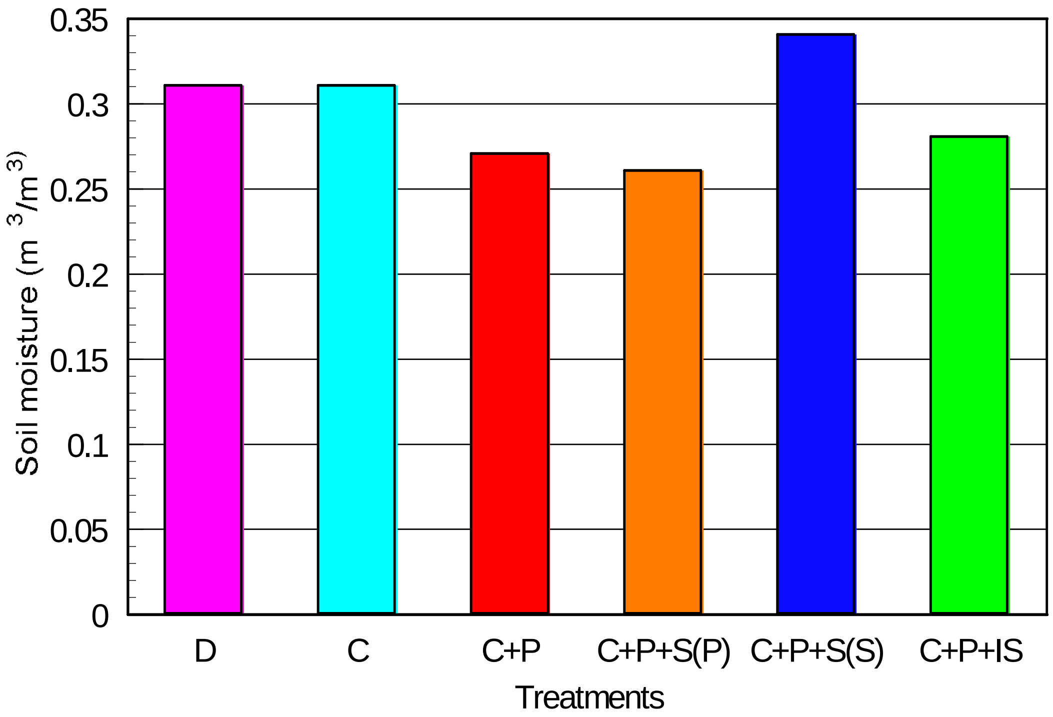


Figure 3.2.13. Soil moisture under different cultivation techniques in 2001

Table 3.2.4. Soil moisture (m^3/m^3) at 6 cm soil depth with F, P and LSD values over the 2000 cropping season. Values are the mean of 10 measurements on each plot. Different letters denotes a significant difference

DAS	F	P	LSD (m^3/m^3)	D	C	C+P	C+P+S(P)	C+P+S(S)	C+P+IS
9	12.636	<0.001	0.086	0.27b	0.25b	0.11a	0.09a	0.29b	0.07a
23	65.787	<0.001	0.039	0.20b	0.17b	0.068a	0.062a	0.31c	0.036a
30	11.985	<0.001	0.065	0.29bc	0.32cd	0.23ab	0.22a	0.36d	0.16a
43	26.368	<0.001	0.051	0.12a	0.11a	0.14a	0.12a	0.33c	0.20b
56	8.632	<0.001	0.103	0.31cd	0.31cd	0.15ab	0.22bc	0.35d	0.11a
69	4.923	<0.011	0.099	0.26ab	0.24a	0.16a	0.22a	0.36b	0.17a
82	21.909	<0.001	0.057	0.35c	0.35c	0.26b	0.19a	0.39c	0.18a
97	11.261	<0.001	0.078	0.37b	0.35b	0.20a	0.22a	0.36b	0.20a
112	9.721	<0.001	0.0077	0.16a	0.17a	0.20a	0.18a	0.37b	0.22a
127	9.115	<0.001	0.078	0.32b	0.28b	0.14a	0.18a	0.32b	0.29b

Table 3.2.5. Soil moisture (m^3/m^3) at 6 cm soil depth with F, P and LSD values over the 2001 cropping season. Values were the mean of five measurements on each plot. Different letters denotes a significant difference

DAS	F	P	LSD (m^3/m^3)	D	C	C+P	C+P+S (P)	C+P+S (S)	C+P+IS
10	4.351	0.017	0.045	0.32 a	0.31a	0.29a	0.28a	0.36b	0.30a
20	31.982	<0.001	0.037	0.35b	0.34b	0.24a	0.23a	0.36b	0.22a
27	9.4	<0.001	0.042	0.28	0.25	0.26	0.23	0.35	0.25
37	5.565	0.007	0.045	0.30	0.28	0.27	0.23	0.32	0.24
52	8.162	<0.001	0.035	0.35	0.35	0.31	0.33	0.38	0.29
67	8.956	<0.001	0.051	0.24	0.27	0.18	0.19	0.31	0.25
82	13.456	<0.001	0.040	0.33	0.32	0.24	0.24	0.35	0.29
97	2.264	0.114	-	0.34	0.35	0.31	0.28	0.33	0.27
127	1.252	0.345	-	0.31	0.33	0.33	0.32	0.36	0.34

The double-ridge polythene mulch used in this experiment was designed to channel any intercepted rainfall into the stem base, therefore to investigate any possible effects. Readings were from the plant base and under polythene. The readings started from seedling thinning. Measurements were seven times in 2000 and five in 2001.

Fig 3. 2,14 The soil moisture around the maize root base and under the polyethene in 2000.

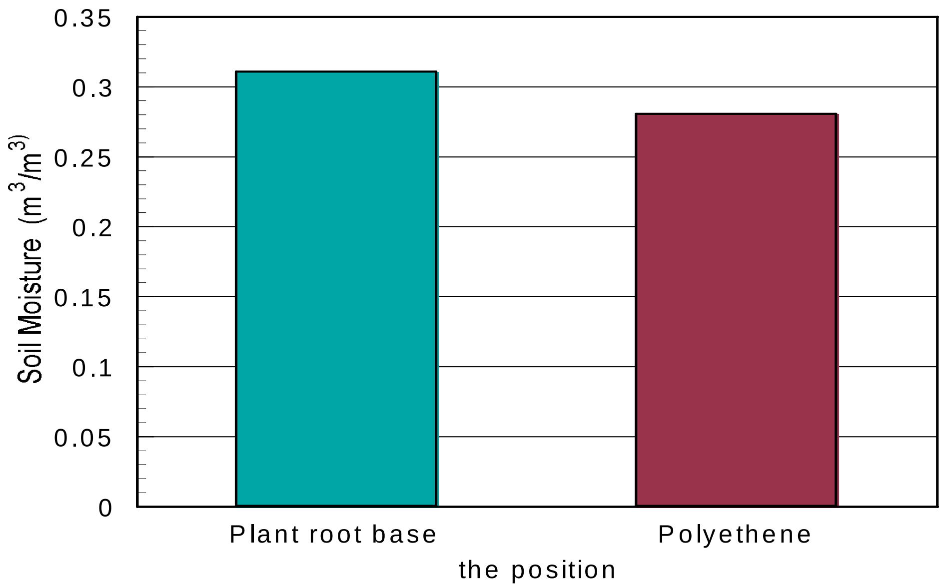


Fig 3. 2.15 The soil moisture around the maize root and under the polyethene in 2001.

Figures 3.2.14 and 3.2.15 are seasonal mean values of 2000 and 2001, respectively. Considering the results from both years, the soil moisture around the plant root base was higher than under polythene. Soil moisture around the plant base was 10.7% and 30.0% more compared with soil moisture under polythene in 2000 and 2001, respectively.

Soil Moisture by Probe Profile

During the 2001 cropping season, soil moisture was also measured by Probe Profile. The profile probe PR1 was established in the middle of each plot before sowing. Data were collected at 10, 20, 30, 40 and 100 cm depths at each measurement (Figure 3.2.16 A-E).

Soil moisture had different patterns under this measurement. At 10 cm soil depth, C and C+P+IS had higher soil moisture, lower soil moisture was on D and C+P. At 20 cm soil depth, C+P+S (S) had higher soil moisture, the lower soil moisture was on D, C+P and C. At 30 cm soil depth, C+P+S (S) still had higher soil moisture, the lower soil moisture was on C. At 40 cm soil depth, C and C+P had higher soil moisture, the lower was on C+P+IS. At 100 cm soil depth, C+P and P+IS had higher soil moisture and the lowest soil moisture was on C.

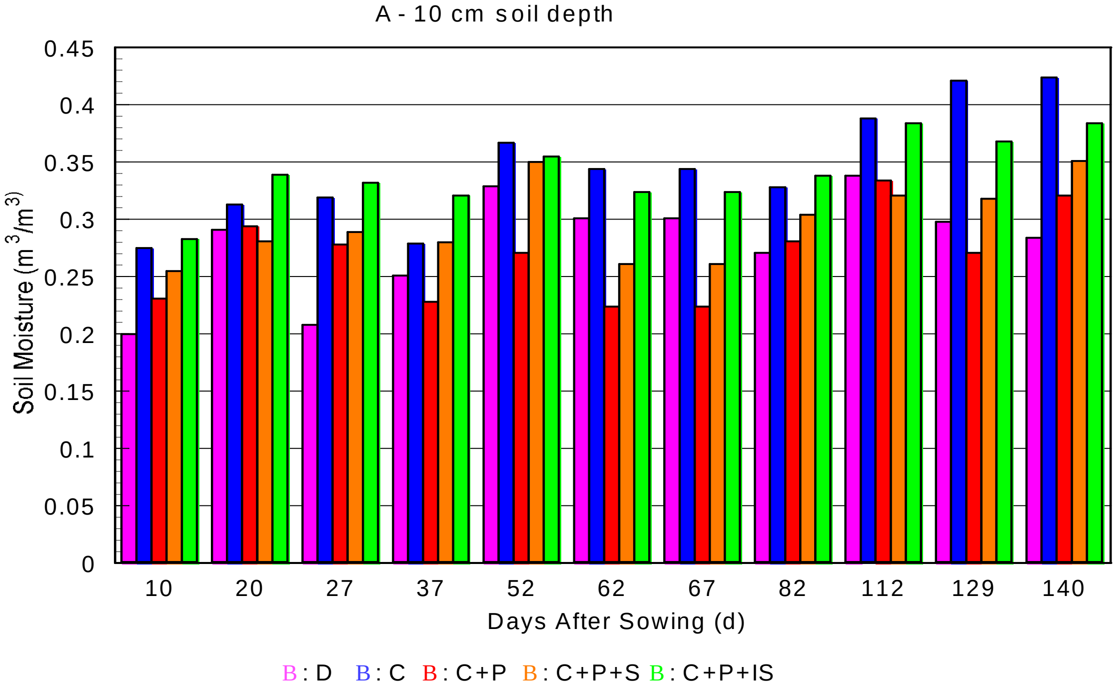
Soil Matric Potential

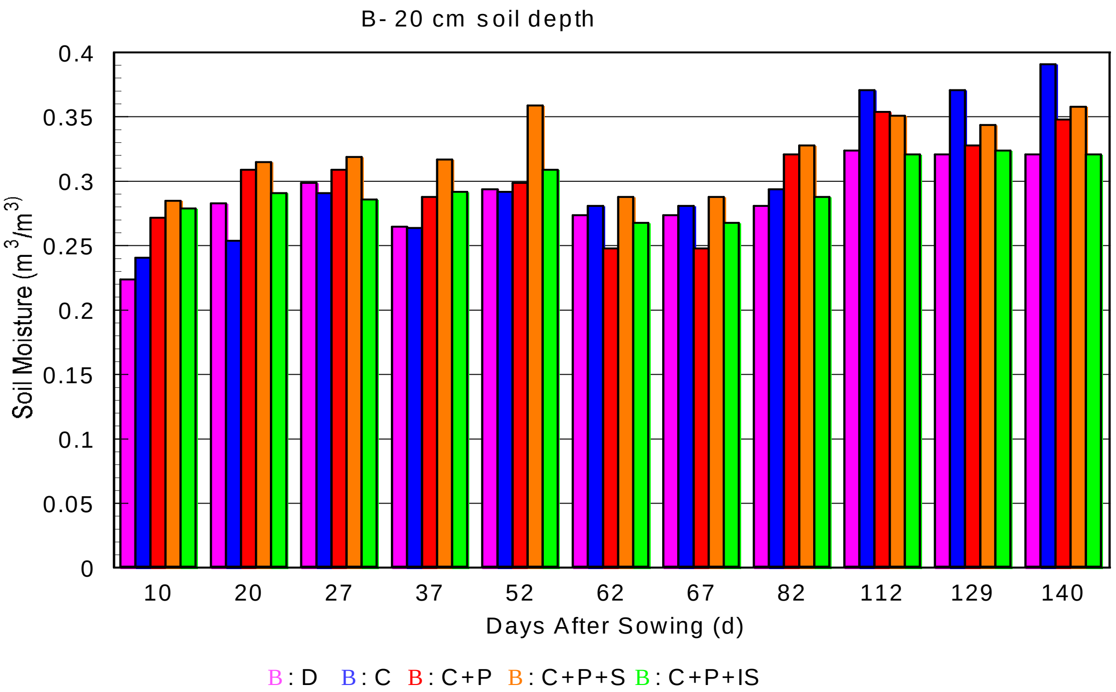
Soil matric potential was also measured during both the 2000 and 2001 cropping seasons (Table 3.2.6). Measurements were made on three plots only, first C, second C+P and third C+P+S (S). The probe was buried at 10 cm depth without replicates, because of the lack of equipment. In both 2000 and 2001, no treatment differences in soil matric potential were found, most readings were 0, which means no water stress for both cropping seasons. This accords closely with soil moisture measurements.

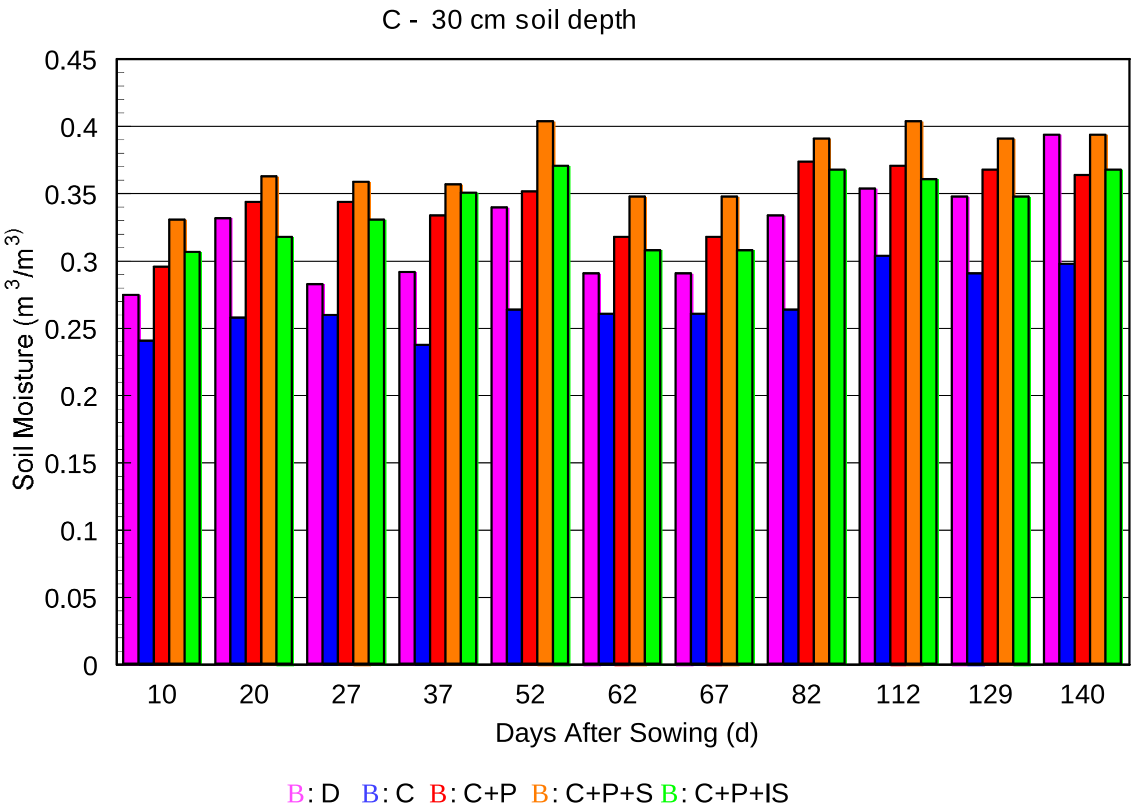
Table 3.2.6. Soil matric potential (Kpa) under three treatments during the 2000 and 2001 seasons

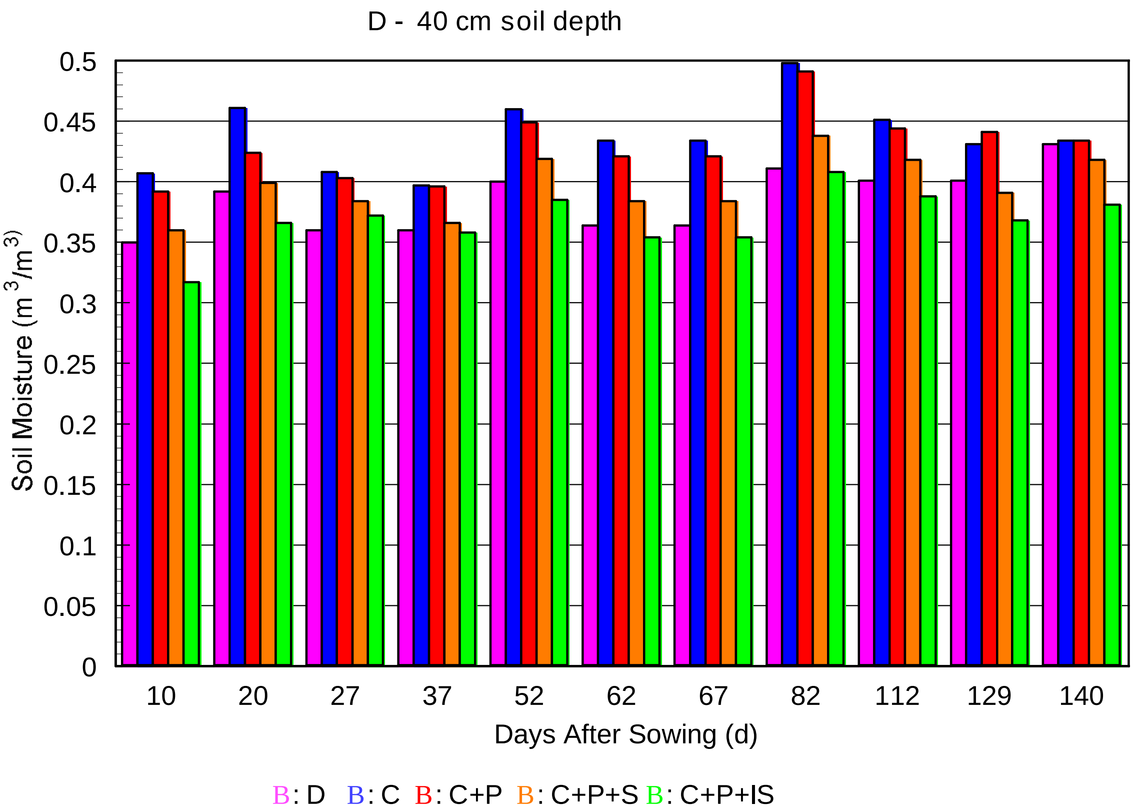
DAS	2000			DAS	2001		
	C	C+P	C+P+S		C	C+P	C+P+S
23	-3	-16	-7	10	0	0	0
30	0	0	0	27	0	0	0
44	0	-8	0	37	0	-7	-7
57	0	0	0	53	0	0	0
70	0	0	0	68	0	0	0
82	0	0	0	84	-3	0	0
83	0	0	0	99	0	0	0
98	0	0	0	130	-45	0	0
99	0	0	0	143	-30	0	0
113	0	0	0				

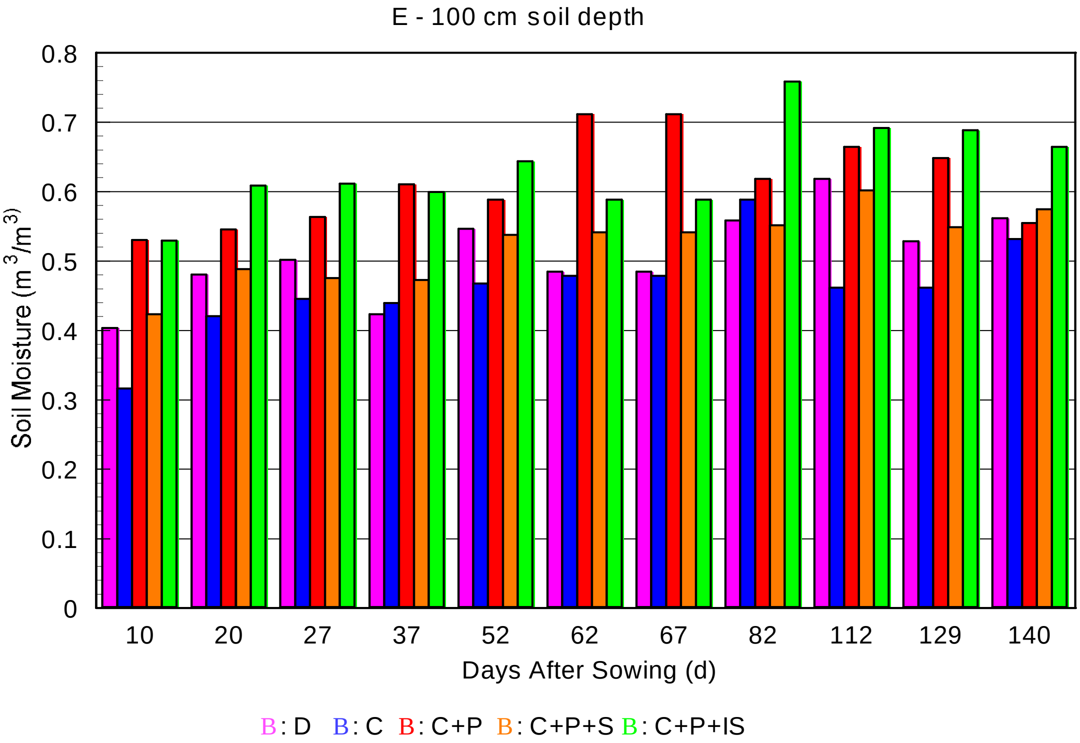
Figure 3.2.16. Soil moisture at different soil depths under different cultivation techniques by Probe profile during the 2001 cropping season






C - 30 cm soil depth
Soil Moisture (m 3/m3)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
10
20
27
37
52
62
67
82
112
129
140
Days After Sowing (d)
B: D B: C B: C+P B: C+P+S B: C+P+IS


D - 40 cm soil depth
Soil Moisture (m 3/m3)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
10
20
27
37
52
62
67
82
112
129
140
Days After Sowing (d)
B: D B: C B: C+P B: C+P+S B: C+P+IS



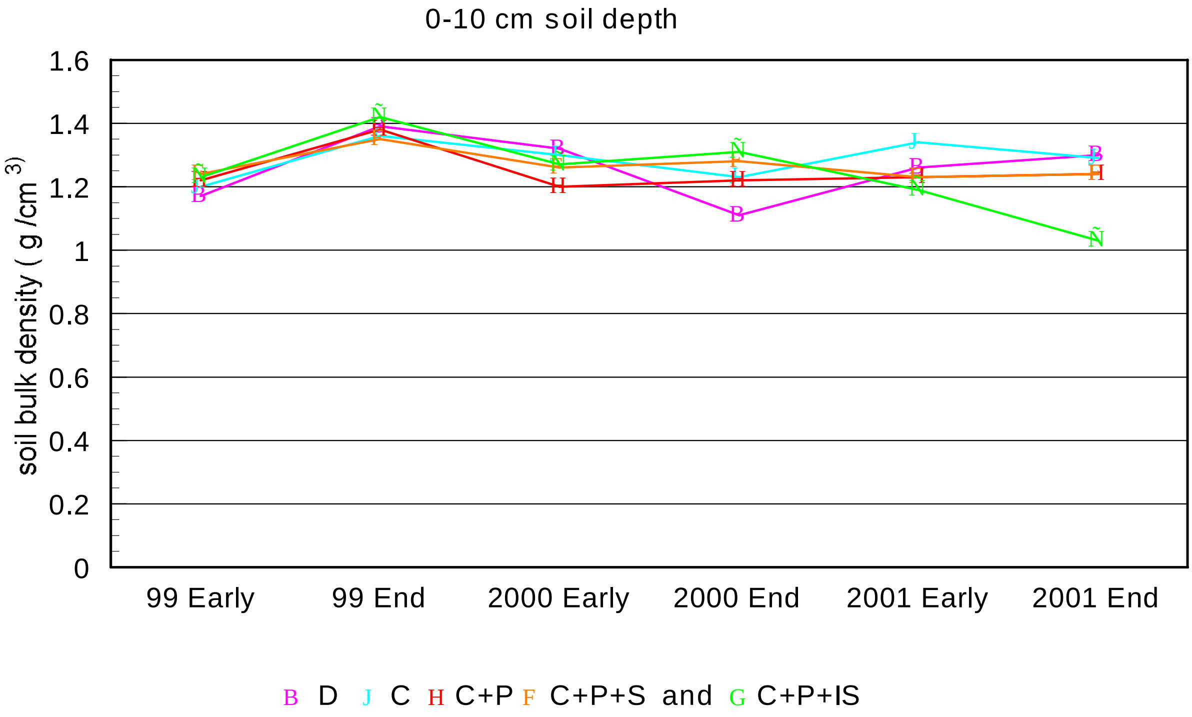
3.3 Soil bulk density

Soil bulk density measurements were taken twice each year, the first measurement was taken at the beginning of the growing period, while the second was taken close to harvest. For each sampling time, three replicate bulk density were taken from three positions (upper, middle and bottom) of each plot at two soil depths, 0-10 cm and 10-20 cm. The exception was the beginning of 1999, when just one soil depth (0-10 cm) sample was taken, due to bulk density core shortage. Ideally, all treatments should be subjected to the same levels of disturbance from weeding and fertility, but different cultivations limited this operation. The mulched plots were disturbed by hand, the plots with no mulch were disturbed by hoeing. Data for each measurement were subject to one way ANOVA. Tables 3.3.1 and 3.3.2 show the significant differences for the 2000 and 2001 seasons, respectively.

Considering the patterns of different treatments from Figure 3.3.1 over three experimental years, C+P+S treatment has a small change at 0-10 cm soil depth, followed by C+P treatment. The largest change was on D treatment. After three years cultivation, the bulk density of C+P+IS treatment seemed to decrease, compared with the value at the beginning. This was probably due to total plot cover (polythene and soybean plant cover) protecting the soil from raindrop compaction. This was repeated on the C+P+S treatment. The soil bulk density at 10-20 cm soil depth had relatively slight change compared with 0-10 cm soil depth, suggesting that the soil surface was easily disturbed by cultivation, weeding, fertilizing and rainfall than deeper soil.

No significant treatment effects were found either at the beginning or end of the season in 1999 on soil bulk density, but in terms of change over the season, some trends were found (Table 3.3.3). At the end of the season, soil bulk density increased on all treatments, the largest increase occurred on the downslope treatment, then the C+P+IS treatment and the smallest increase was on C+P+S treatment. All the latter increases possibly resulted from compaction through raindrop impact and associated decreases in surface roughness.

Figure 3.3.1. Mean soil bulk density on different treatments during three cropping seasons



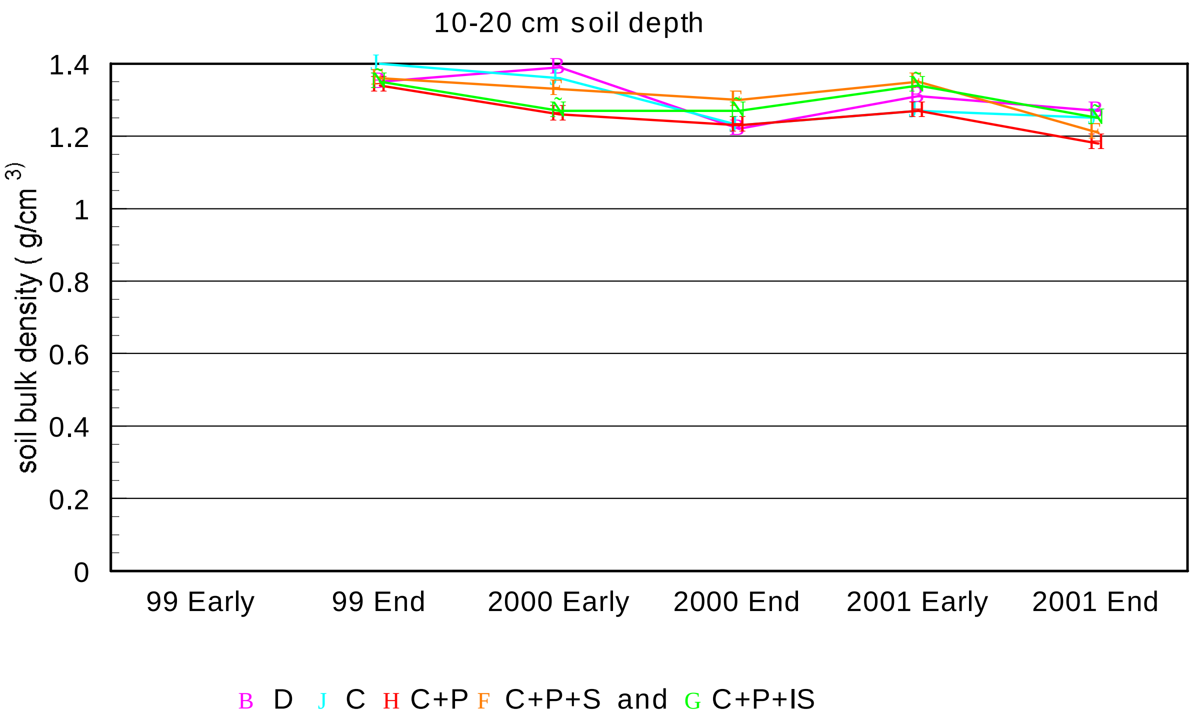


Table 3.3.1. Soil bulk density (g/cm^3) at 0-10 and 10-20 cm soil depth at the beginning and end of the 2000 cropping season with F values. Different letters denote significant differences (n = 9)

Date	28/06/2000		25/09/2000	
Treatments	Soil depth (cm)			
	0-10	10-20	0-10	10-20
D	1.32b	1.39b	1.11a	1.22
C	1.31b	1.38b	1.24b	1.22
C+P	1.20a	1.26a	1.21b	1.24
C+P+S	1.26ab	1.33ab	1.28b	1.30
C+P+IS	1.27b	1.27a	1.31b	1.27
F value	4.796	3.266	4.503	1.380
P value	0.003	0.021	0.004	0.258

Soil bulk density during the 2000 season is shown in Table 3.3.1. Soil bulk density of C+P, C+P+S and C+P+IS treatments increased little during the later period. The soil bulk density of downslope (D) and contour cultivation (C) with no mulch decreased, the reason was before this measurement the soil was loosened by weeding. Before the soil was disturbed, the soil bulk density of mulch treatments was less than downslope and contour cultivation with no mulch. A significant difference was found between the mulch treatments and no mulch treatments at 0-10 cm soil depth, C+P had least soil bulk density, then C+P+S treatment, and the more compact soil was on D and C treatments. Similar patterns were found at 10-20 cm soil depth, although soil bulk density at this depth was higher than at 0-10 cm soil depth.

Significant differences were also found between the mulch treatments and no mulch treatments at 0-10 cm soil depth at the later season. D treatment had a smaller bulk density compared with other treatments, followed by C treatment, the reason was possibly the soil was loosened for weeding. No significant difference between treatments was found at 10-20 cm soil depth for the later season.

Table 3.3.2. Soil bulk density (g/cm^3) at 0-10 cm and 10-20 cm soil depth at the beginning and end of the 2001 cropping season with F value. Different letters denote a significant difference (n = 9)

Date	23/06/2001		25/09/2001	
Soil depth (cm) / Treatment	0-10	10-20	0-10	10-20
D	1.26b	1.31	1.30b	1.27
C	1.34c	1.27	1.29b	1.25
C+P	1.23ab	1.27	1.24b	1.18
C+P+S	1.23ab	1.35	1.24b	1.21
C+P+IS	1.19a	1.34	1.03a	1.25
F value	8.123	0.82	20.416	1.822
P value	0.003	0.541	<0.01	0.201
LSD	0.060	0.134	0.077	0.086

The patterns of soil bulk density during 2001 (Table 3.3.2) had little variation compared with the 2000 season. The significant difference was found between the mulch treatments and no mulch treatments at 0-10 cm soil depth. C+P+IS had the lowest bulk density, then C+P+S and C+P treatments. The more compact soil was on C and D treatments. Similar trends were found in the later season. There was no significant difference at 10-20 cm soil depth at both the beginning and end of the cropping season.

Table 3.3.1. Mean soil bulk density (g/cm^3) changes at the 0-10 and 10-20 cm soil depths at the end of cropping season for different treatments during three years experiments (n = 3)

Treatments	1999		2000		2001	
	0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm
D	0.22	-	-0.21	-0.17	0.04	-0.04
C	0.16	-	-0.07	-0.16	-0.05	-0.02
C+P	0.16	-	0.01	-0.02	0.01	-0.09
C+P+S	0.11	-	0.02	-0.03	0.01	-0.14
C+P+IS	0.19	-	0.04	0	-0.16	-0.09

3.4 Soil nutrients

Soil samples from May 1999 to October 2001 were taken to assess whether any significant temporal changes had occurred. The following chemical properties were analysed: total N, P, K, available N, P, K, organic matter, soil pH and exchangeable Ca, Mg, Fe, Cu, Zn and Al. Generally, no significant effects treatments were observed, so the following descriptions are based on apparent differences only.

3.4.1 Total N, P and K

Total N, P and K over 1999 and 2000 cropping seasons are presented in Tables 3.4.1 and 3.4.2, respectively. At the end of 1999, there were small decreases in total N for all treatments, except C+P+IS. Conversely, total K increased on D, C and C+P, but not on C+P+S and C+P+IS. Total P was constant and consistent for all the treatments, which could be because P is difficult to mobilize and easy to fix onto other composites (Table 3.4.1). Within 2000, at the end of the season, all treatments increased in total N, except D, the largest increase occurred in C+P+IS. Total K followed the same pattern with the largest increase in C+P+S, possibly enhanced by mulch decay (Table 3.4.2). However, it was surprising that total N and P decreased, while total K increased in 2000, compared with 1999.

Table 3.4.1. Mean soil total N, P and K (%) at the beginning and end of the 1999 cropping season for the composite samples. NS relates to P >0.05 (n = 3)

Treatments	Total N			Total P			Total K		
	Beg.	End	Change	Beg.	End	Change	Beg.	End	Change
D	0.26	0.23	-0.03	0.030	0.023	-0.007	1.12	1.15	0.03
C	0.25	0.23	-0.02	0.033	0.033	0.00	1.35	1.38	0.03
C+P	0.26	0.25	-0.01	0.050	0.030	-0.02	1.14	1.39	0.25
C+P+S	0.27	0.24	-0.03	0.040	0.033	-0.007	1.20	1.06	-0.14
C+P+IS	0.24	0.25	+0.01	0.040	0.040	0.00	0.93	0.82	-0.11
F	2.24	1.03	1.184	2.65	2.75	1.765	0.43	0.61	0.139
P	NS	NS	NS	NS	NS	NS	NS	NS	NS

Overall, the only treatment to exhibit an increase in total N was intercropping in 1999, and this effect was consistent in 2000 and had the largest increase. Total K in C+P+S and C+P+IS exhibited different patterns, in 1999 both of them decreased, but in 2000 increased.

Table 3.4.2. Mean soil total N, P and K (%) at the beginning and end of the 2000 cropping season for the composite samples (n = 3)

Treatments	Total N			Total P			Total K		
	Beg.	End	Change	Beg.	End	Change	Beg.	End	Change
D	0.083	0.057	-0.026	0.015	0.018	0.003	2.53	2.52	-0.01
C	0.090	0.093	0.003	0.024	0.019	-0.005	1.95	2.55	0.60
C+P	0.093	0.103	0.01	0.020	0.019	-0.001	1.21	2.57	1.36
C+P+S	0.080	0.083	0.003	0.017	0.024	0.007	0.85	2.58	1.73
C+P+IS	0.087	0.11	0.024	0.024	0.019	-0.005	1.47	2.51	1.04
F	0.417	2.579	1.606	0.958	0.344	0.448	1.55	0.02	2.396
P	NS	NS	NS	NS	NS	NS	NS	NS	NS

3.4.2 Available N, P and K

The change in available N, P and K tended to be much more variable compared with total forms. Treatment effects were very difficult to distinguish. There were very few similarities among the treatments. However, in terms of changes in available N and P in both the 1999 and 2000 seasons, the value of all treatments decreased. In 1999, for N, the least decrease was C+P and the largest reduction was in D. For P, the least reduction was C+P+D and C+P+IS, while the greater decrease was on C+P (Table 3.4.3). In 2000, the least decrease of available N was on C+P+IS, C+P+S, and then C+P, C, and the greatest reduction was still on D. Available P followed the same pattern as in 1999 (Table 3.4.4). No clear treatment effects were evident with available K, it was very variable between two years and without common treatment effects.

Table 3.4.3. Mean soil available N, P and K (mg/kg) at the beginning and end of the 1999 cropping season for the composite samples (n = 3)

Treatments	Available N			Available P			Available K		
	Beg.	End	Change	Beg.	End	Change	Beg.	End	Change
D	247.7	152.1	-95.6	25.3	7.4	-17.9	87.4	83.8	-3.6
C	217.9	157.6	-60.3	24.8	6.7	-18.1	105.5	107.7	2.2
C+P	222.6	184.8	-37.8	30.1	9.8	-20.3	118.4	81.2	-37.2
C+P+S	226.6	176.2	-50.4	20.1	4.8	-15.3	81.0	83.0	2.0
C+P+IS	243.6	170.0	-73.6	23.3	7.3	-16.0	114.3	90.0	-24.3
F	0.223	0.988	0.374	0.42	0.70	0.173	0.53	0.419	1.066
P	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 3.4.4. Mean soil available N, P and K (mg/kg) at the beginning and end of 2000 the cropping season for the composite samples (n = 3)

Treatments	Available N			Available P			Available K		
	Beg.	End	Change	Beg.	End	Change	Beg.	End	Change
D	176.97	131.13	-45.83	8.56	4.99	-3.57	62.04	65.28	3.24
C	180.67	136.27	-44.40	8.82	5.69	-3.13	57.04	82.58	25.54
C+P	191.55	154.53	-37.03	9.79	6.01	-3.78	65.53	61.29	-4.24
C+P+S	147.70	120.20	-27.50	6.72	5.00	-1.72	79.95	63.97	-15.98
C+P+IS	177.83	155.07	-22.77	5.66	4.52	-1.14	67.17	81.90	14.73
F	0.791	0.299	0.097	0.542	0.24	0.704	0.608	0.525	0.965
P	NS	NS	NS	NS	NS	NS	NS	NS	NS

3.4.3 Soil organic matter and pH

For soil organic matter and pH, there were small changes over two seasons with few treatment effects (Tables 3.4.5 and 3.4.6). The reason probably was that on each plot the same amount of fertilizer and manure are added each year. Although straw mulch and soybean were added in the C+P+S and C+P+IS plots, respectively, it was probably insufficient to contribute to notable changes in just two seasons.

Table 3.4.5. Mean soil organic matter (%) and pH value at the beginning and end of the 1999 cropping season for the composite samples (n = 3)

Treatments	Organic matter			pH		
	Beg.	End	Change	Beg.	End	Change
D	1.14	1.19	0.05	5.07	5.05	-0.02
C	1.11	1.29	0.18	5.29	5.29	0.00
C+P	1.26	1.30	0.04	5.13	5.12	-0.01
C+P+S	1.23	1.30	0.07	5.24	5.25	-0.01
C+P+IS	1.26	1.30	0.04	5.17	5.17	0.00
F	2.083	0.980	1.429	0.48	0.676	0.350
P	NS	NS	NS	NS	NS	NS

Table 3.4.6. Mean soil organic matter (%) and pH value at the beginning and end of the 2000 cropping season for the composite samples (n = 3)

Treatments	Soil organic matter			pH		
	Beg.	End	Change	Beg.	End	Change
D	1.27	1.10	-0.17	5.06	5.24	0.18
C	1.18	1.13	-0.05	5.18	5.12	-0.06
C+P	1.17	1.19	0.02	5.52	5.53	0.01
C+P+S	1.29	1.14	-0.15	5.40	5.32	-0.08
C+P+IS	1.17	1.20	0.03	5.38	5.33	-0.05
F	0.370	0.336	1.263	2.782	0.922	1.551
P	NS	NS	NS	NS	NS	NS

At the beginning of the 2001 cropping season, there were no significant treatment effects (Table 3.4.7). After three years of experiments there were no significant treatment effects for these eight selected elements, as expected. However, some interesting findings were still found in C+P+S and C+P+IS treatments. C+P+IS increased total K and available N, but not P. This may be the contribution from decaying soybean leaves and roots. C+P+S increased available K, possibly enhanced by decomposed straw (Table 3.4.8).

Table 3.4.7. Mean soil nutrients at the beginning of the 2001 cropping season (n = 3)

Samples	Treatment	pH	Soil organic Matter (%)	Total N (%)	Total P (%)	Total K (%)	Available N (mg/kg)	Available P (mg/kg)	Available K (mg/kg)
Composite	D	5.14	1.16	0.093	0.11	2.29	139.28	37.32	118.84
	C	5.63	1.20	0.097	0.11	2.03	150.77	32.05	110.19
	C+P	5.38	1.10	0.103	0.10	2.07	145.43	39.10	114.12
	C+P+S	5.45	1.07	0.083	0.10	2.02	138.12	33.15	108.79
	C+P+IS	5.26	1.15	0.100	0.12	1.93	148.46	37.54	121.87
F		1.36	1.203	0.434	0.58	0.224	0.651	0.456	0.162
P		NS	NS	NS	NS	NS	NS	NS	NS

Table 3.4.8. Mean soil nutrients at the end of the 2001 cropping season (n = 3)

Treatment	pH	Soil organic Matter (%)	Total N (%)	Total P (%)	Total K (%)	Available N (mg/kg)	Available P (mg/kg)	Available K (mg/kg)
D	4.97	1.33	0.09	0.05	2.20	108.19	17.10	60.29
C	5.17	1.24	0.07	0.05	2.46	93.50	13.01	73.13
C+P	5.23	1.24	0.11	0.04	2.31	115.48	15.78	73.72
C+P+S	5.20	1.29	0.10	0.04	2.51	111.19	15.56	91.66
C+P+IS	5.03	1.31	0.11	0.04	2.75	119.67	10.51	67.98
F	1.073	0.188	1.131	0.198	0.383	1.160	2.019	0.778
P	NS	NS	NS	NS	NS	NS	NS	NS

Soil nutrients change of top and bottom position of the plot

Before starting the experiment (April 1999), no significant difference was found between the bottom and top position of plot among these eight selected elements (Table 3.4.9). However, after one season's trial, significant treatment effects were found for total N and organic matter. All the treatments, except C+P, were found to have high concentrations at the bottom compared with the top position. This suggested total N and soil organic matter moved from the top to bottom. However, polythene mulch impeded this movement for total N and soil organic matter (Table 3.4.9).

Table 3.4.9. Soil nutrient differences between the bottom and top position of plots in 1999 (n = 3)

Soil samples	Treatment	Total N (%)	Total P (%)	Total K (%)	Avail-able N (mg/kg)	Available P (mg/kg)	Available K (mg/kg)	SOM (%)	pH
April	D	-0.020	0.00	0.36	-3.40	11.16	-48.66	0.04	0.24
	C	-0.027	0.00	0.40	5.59	2.55	31.21	0.08	-0.14
	C+P	-0.060	0.01	0.23	-31.49	6.94	-18.01	0.04	-0.03
	C+P+S	0.013	0.00	-0.63	-43.31	-0.41	-8.78	-0.11	0.08
	C+P+IS	0.020	0.00	-0.19	39.2	8.59	-37.03	0.14	0.01
	F	1.45	1.43	0.58	1.02	0.45	1.71	0.50	1.56
	P	0.29	0.29	0.69	0.44	0.77	0.23	0.74	0.26
October	D	0.02	0.01	-0.13	-6.89	-0.92	-13.03	-0.02	0.22
	C	0.01	-0.01	-0.20	-6.83	2.30	-14.77	0.08	-0.15
	C+P	-0.04	0.00	0.05	-22.64	-0.13	-46.72	-0.31	-0.06
	C+P+S	0.03	0.00	0.33	12.1	3.66	-4.4	0.14	-0.01
	C+P+IS	0.01	0.01	0.55	-6.23	5.77	-18.67	0.01	0.00
	F	3.59	1.19	2.28	0.44	0.61	1.22	3.86	1.06
	P	0.046	NS	NS	NS	NS	NS	0.038	NS

In 2000, there were no distinct element differences among the treatments (Table 3.4.10). Generally, total forms were stable, while available forms were variable. The only treatment had no difference in available N and P was C+P+S, the other treatments had higher concentration of these two elements on the bottom than the top position.

Table 3.4.10. Soil nutrient difference between the top and bottom of plots 2000 (n = 3)

Soil samples	Treatment	Total N (%)	Total P (%)	Total K (%)	Available N (mg/kg)	Available P (mg/kg)	Available K (mg/kg)	SOM (%)	pH
April	D	0.02	0.00	0.03	-1.70	0.11	-19.16	-0.09	-0.08
	C	-0.01	0.00	-0.71	24.70	1.47	-7.71	0.05	-0.33
	C+P	0.00	0.00	-0.67	-17.67	-2.23	-31.43	0.08	-0.05
	C+P+S	0.00	0.00	-0.09	-6.40	-0.04	-24.62	0.10	0.01
	C+P+IS	0.01	0.00	-0.32	5.43	2.23	-6.37	-0.02	-0.13
	F	0.37	0.25	0.55	0.24	0.38	1.07	0.63	0.91
	P	0.83	0.90	0.70	0.91	0.82	0.42	0.65	0.50
October	D	0.03	0.00	-0.22	30.13	1.58	-29.4	0.03	-0.11
	C	0.02	0.00	-0.28	5.07	0.08	-18.00	0.15	-0.04
	C+P	0.0	0.00	-0.75	50.2	1.56	-29.45	-0.1	-0.04
	C+P+S	-0.07	0.00	-0.02	-13.0	-1.12	-28.03	0.32	-0.12
	C+P+IS	-0.01	0.00	-0.36	39.57	3.91	-10.06	0.13	0.08
	F	2.93	1.17	0.30	0.98	1.29	0.20	1.75	0.34
	P	NS	NS	NS	NS	NS	NS	NS	NS

In 2001 D and C treatments had more available N and SOM on the bottom than top position, suggesting that these two soil constituents had probably moved downslope (Table 3.4.11).

Table 3.4.11. Soil nutrient differences between the top and bottom position of plots in April 2001 (n = 3)

Treatment	Total N (%)	Total P (%)	Total K (%)	Availab le. N (mg/kg)	Avail-Able- P (mg/kg)	Avail-able K (mg/kg)	SOM (%)	pH
D	0.01	0.00	-0.20	2.53	-7.34	-19.77	0.06	0.06
C	-0.02	0.00	-0.21	5.99	-4.33	-22.94	0.04	-0.03
C+P	0.00	0.00	-0.34	-15.63	-2.63	-25.40	-0.05	-0.03
C+P+S	0.02	0.00	-0.17	-5.40	-6.30	-38.82	-0.01	0.05
C+P+IS	-0.01	0.00	-0.10	-28.41	-3.03	-42.91	-0.03	-0.03
F	1.42	0.99	0.25	1.34	0.16	0.42	0.91	0.09
P	NS	NS	NS	NS	NS	NS	NS	NS

Soil nutrient changes under different covers

Figure 3.4.1 shows soil nutrient changes under different covers. An interesting result was found that under polythene mulch there was higher available N, P and K than in the bare row within the plot. Straw mulch enhanced available K more than under polythene mulch, even when fertilizer was applied in the polythene row. Soybean intercrop increased soil available P and K. Available N under soybean row was less compared with polythene row, but it increased available N more than the bare row.

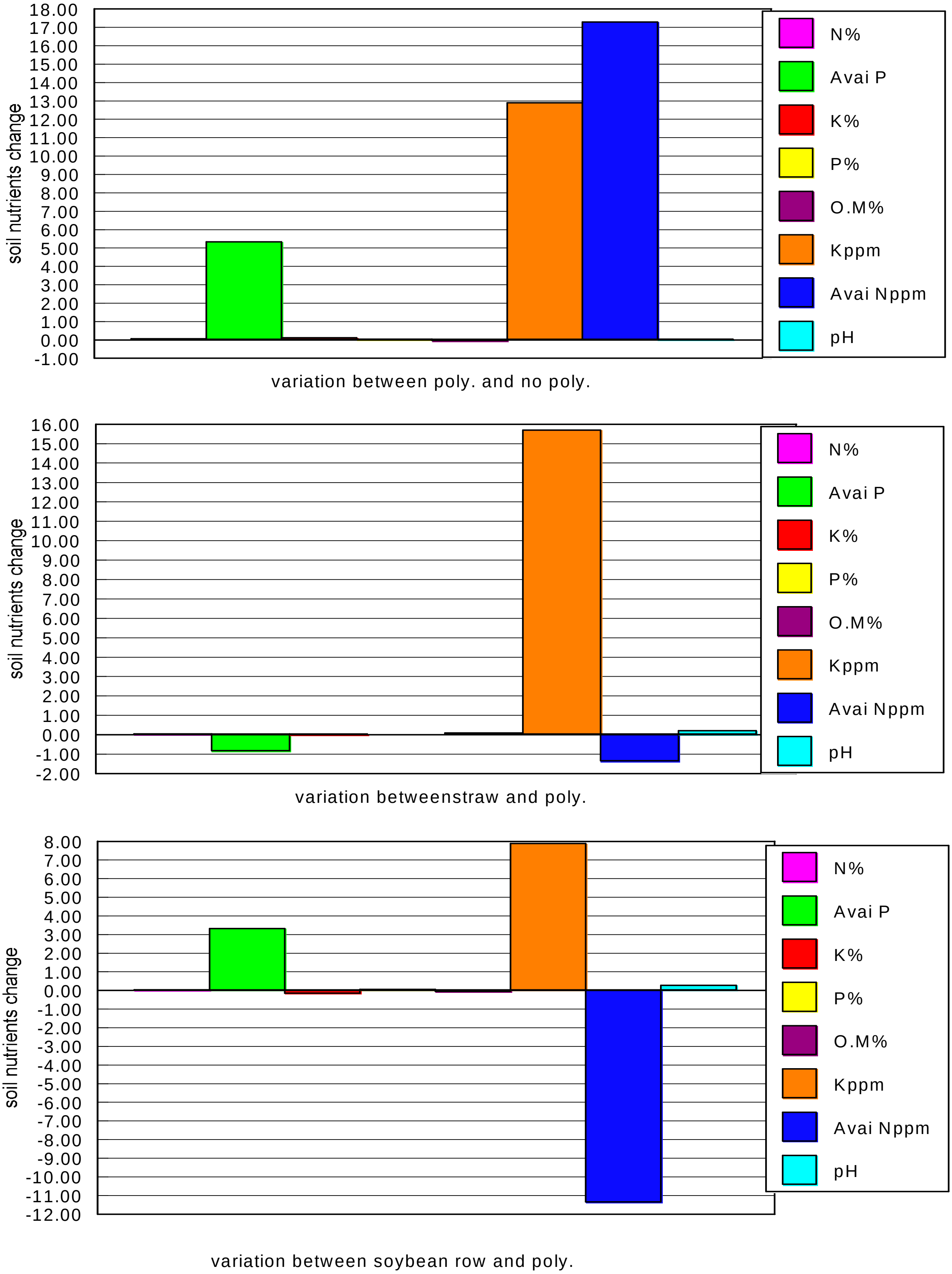


Figure 3.4.1. Soil nutrient changes under different covers.

Other nutrient analyses by ICP

Before starting the experiment, concentrations of Al, Ca, Cu, Fe, Mg and Zn were very variable. A significant difference was found for Al. C+P+IS plot had a highest Al, then C; the least value was C+P and D. Although no significant difference was found for other elements, there were some differences between them (Table 3.4.12). After two years of experiments, the difference between them decreased, except Ca. C+P+IS had significantly higher Ca (Table 3.4.13).At the end of the 2001 experiment, there were no significant treatment differences (Table 3.4.14) and the value was variable. This suggested that the plot had a different nutrient history.

Table 3.4.12. Other elemental analyses by ICP in April 1999

Treat-ments	A (ppm)	Ca (mg/100g)	Cu (ppm)	Fe (ppm)	Mg (mg/100g)	Zn (ppm)
D	0.33a	3.75	0.51	4.92	0.86	0.15
C	1.93ab	5.27	0.92	7.16	1.55	0.35
C+P	0.31a	1.3	0.3	2.32	0.52	0.12
C+P+S	1.06a	3.9	0.63	4.74	1.11	0.66
C+P+IS	3.41b	3.93	0.81	4.77	1.35	0.29
	F = 2.847, P<0.05					

Table 3.4.13. Other elemental analyses by ICP in April 2001

Treat-ments	Al (ppm)	Ca (mg/100g)	Cu (ppm)	Fe (ppm)	Mg (mg/100g)	Zn (ppm)
D	0.39	2.58a	0.47	4.09	0.98	0.21
C	0.26	2.52a	0.39	4.04	0.93	0.22
C+P	0.27	2.62a	0.4	3.46	0.73	0.21
C+P+S	0.3	3.16a	0.56	4.45	1.13	0.71
C+P+IS	0.33	5.87b	0.61	6.06	1.8	0.31
		F = 3.875, P<0.05				

Table 3.4.14. Other elemental analyses by ICP in October 2001

Treatments	Al (ppm)	Ca (mg/100g)	Cue (ppm)	Fe (ppm)	Mg (mg/100g)	Zn (ppm)
D	0.39	1.21	0.38	3.42	0.5	0.32
C	0.57	3.36	0.72	5.62	1.18	0.44
C+P(P)	0.4	2	0.42	3.91	0.73	0.35
C+P	0.41	1.93	0.52	3.99	0.76	0.35
C+P+S(P)	0.43	2.87	0.42	4.14	0.93	0.36
C+P+S(S)	0.32	1.42	0.22	2.85	0.57	0.35
C+P+IS(P)	0.75	5.89	0.7	6.95	1.73	0.46
C+P+IS(S)	0.58	3.2	0.43	4.5	1.03	0.42

3. 5 Crop development and yield

Details of vegetative growth and development, yield and other harvest data over three seasons are presented and summarized in this section.

3.5.1 Plant development

Plant height

In 1999 and 2000, plant height was measured from the plant stem base to the extended-leaf tip. In 2001, however, the measurement was changed to measure the distance from the plant root base to the new shoot tip. The change was due to the hypothesis that the latter method would give a better estimate during reproductive growth. In 1999, plant height was measured over the whole crop season. From the results of this measurement, it was conducted that plant height did not show further change after achieving the first plateau, so in both 2000 and 2001, measurements continued until the height stabilized.

Heights during 1999, 2000 and 2001 seasons are shown in Figure 3.5.1, which reports significant treatment effects in all years. In 1999, with polythene and straw mulch (C+P+S) maize developed quicker and final mean plant height was 226.1 cm. Similarly for polythene mulch (C+P) treatment, maximum plant mean height was 222.0 cm. Intercropping with polythene (C+P+IS) mulch also caused quicker canopy development, this treatment appeared to assist soybean to develop a canopy over the plot at an early stage. No significant differences were found between these three treatments for plant height. Conversely, downslope cultivation (D) produced a much slower development and shorter maize canopy. Traditional contour cultivation (C) showed better effects than downslope cultivation, a significant difference ($P < 0.05$) was found on one occasion measurement (on 40 days after sowing, $F = 34.855$, $LSD = 8.68$ cm). There was a significant difference between mulch and no mulch treatments (Table 3.5.1).

The 2000 season show similar trends with the 1999 season, and small differences were found between the treatments. During this season, the quickest maize development was found with polythene mulch (C+P) and the final maize mean plant height was 229.6 cm, followed by intercropping with polythene mulch treatment (C+P+IS), where the final mean plant height was 227.5 cm. Polythene and straw mulch treatment (C+P+IS) also showed evidence of more rapid crop growth and canopy development. No significant plant height differences were found between these three treatments. Downslope cultivation (D) also produced a much slower developing and shorter maize canopy. Traditional contour cultivation (C) showed better effects than downslope cultivation. There were significant differences between the mulch treatments and no mulch treatments (Table 3.5.1).

In 2001, polythene mulch (C+P) maize developed quicker and similar development was apparent for intercropping with polythene mulch treatment (C+P+IS) compared to downslope cultivation (D). Straw mulch (C+P+S) maize also showed evidence of quicker crop growth and canopy development. No significant differences were found between these three treatments in terms of plant height. Traditional contour cultivation (C) showed better effects than downslope cultivation (D) (Table 3.5.1).

Fig3.5.1 Effect of cultivation techniques on plant height with the standard error bar during the 1999, 2000 and 2001 maize growing season: B -D, J -C, H-C+P, F -C+P+S and G-C+P+IS.

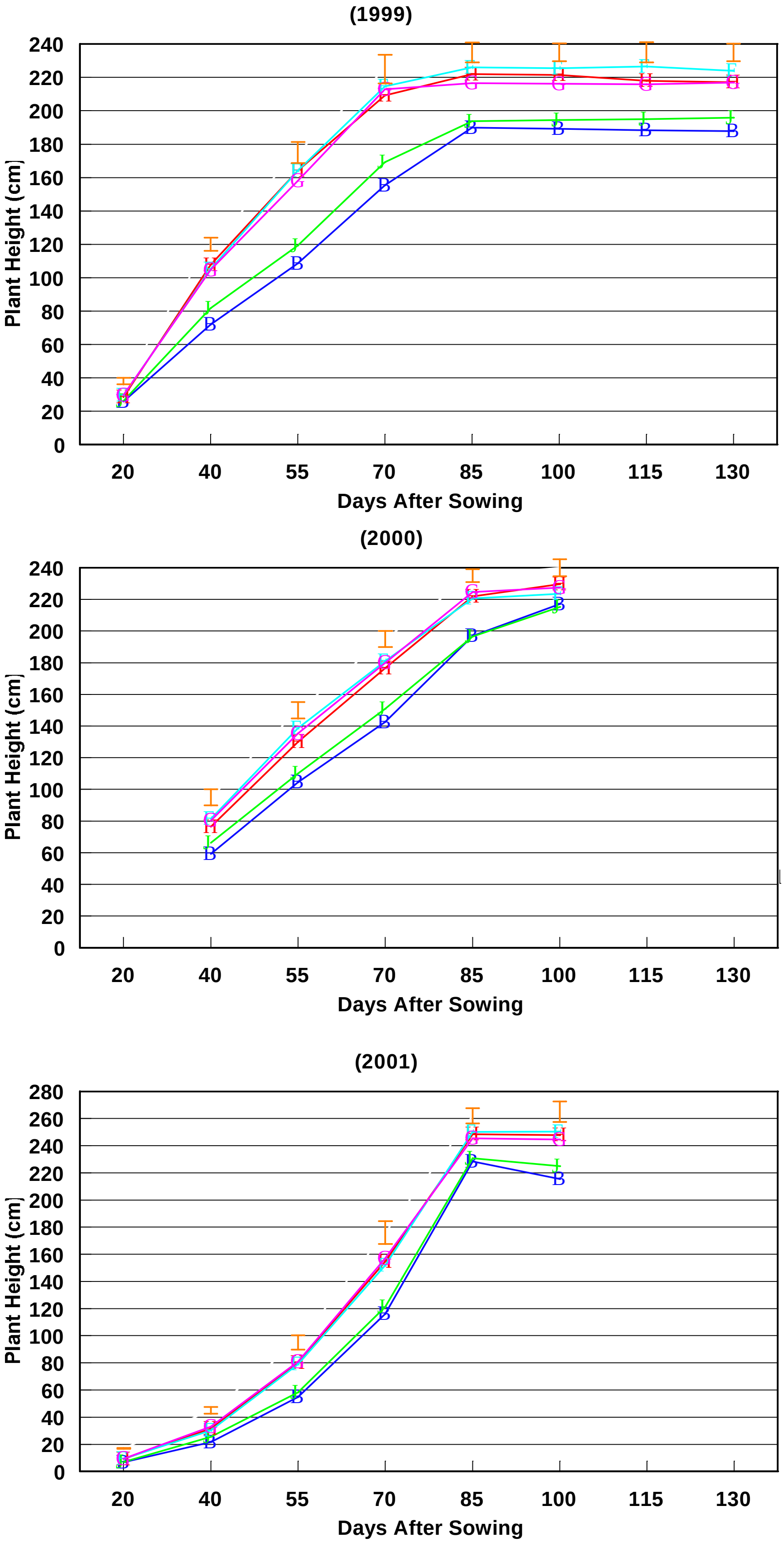


Table 3.5.1. Plant height (cm) during the 1999, 2000 and season. Values are mean of 8 plants (n = 3)

Year	DAS	F	P	LSD (cm)	Treatments				
					D	C	C+P	C+P+S	C+P+IS
1999	20	1.631	0.241	-	25.8	26.1	28.4	29.4	29.5
	40	34.855	<0.001	8.68	71.9a	81.7b	107.6c	105.1c	104.6c
	55	36.688	<0.001	13.94	108.5a	119.2a	164.2b	164.1b	157.9b
	70	20.979	<0.001	19.14	155.4a	169.2a	209.2b	214.6b	212.9b
	85	15.724	<0.001	13.26	189.9a	193.7a	222.0b	226.1b	216.6b
	100	19.200	<0.001	11.85	189.1a	194.4a	221.4b	225.5b	216.2b
	115	14.571	<0.001	13.43	188.3a	195.0a	218.0b	226.6b	215.8b
	130	17.770	<0.001	11.63	187.7a	195.9a	217.0b	223.8b	216.9b
2000									
	40	7.394	0.005	11.17	59.2a	66.3ab	76.5bc	81.4c	80.3c
	55	17.371	<0.001	11.69	104.5a	110.0a	130.0b	138.7b	135.3b
	70	25.046	<0.001	11.38	142.6a	150.8a	176.6b	181.0b	179.9b
	85	24.410	<0.001	9.0	196.9a	196.6a	221.9b	220.5b	224.7b
	100	2.748	0.089	-	217.0	215.3	229.6	223.6	227.5
2001									
	20	33.016	<0.001	0.73	6.7a	7.0a	9.2b	9.4b	9.3b
	40	6.778	0.007	5.72	21.6a	25.6ab	31.6bc	30.3bc	33.0c
	55	11.863	<0.001	11.84	54.8a	58.4a	80.3b	79.0b	80.9b
	70	11.152	<0.001	18.69	116.0a	121.3a	154.6b	151.8b	157.1b
	85	6.742	0.007	12.46	228.4a	230.7a	248.4b	250.2b	245.3b
	100	8.474	0.003	16.76	215.5a	224.9a	247.8b	250.3b	244.6b

Green Leaf Area Index (GLAI)

GLAI values for 1999, 2000 and 2001 seasons are shown in Figure 3.5.2, with full statistical details given in Table 3.5.2. Following similar trends to plant height, the GLAI curves for the 1999 data clearly indicated higher rates of leaf growth under polythene mulch compared to the no mulch treatments. The lowest Leaf Index Growth was on traditional downslope cultivation (D). The difference between treatments was more distinct.

GLAI curves for the 2000 data also clearly indicated higher rates of leaf growth under polythene mulch compared to the no mulch treatments. The lowest GLAI was found with traditional downslope cultivation. The GLAI curves for the 2001 data followed the same pattern before the heavy hail, in which mulch treatments produced significantly higher rate of leaf development and no mulch treatments produced smaller canopies, especially for the D treatment. After the hail, there were no significant treatment effects and the leaves were badly damaged on all plots.

Generally, both plant height and GLAI curves showed that in all treatments, maize grew very fast during the early stage. The Leaf Area Index achieved the maximum value at ~85 days and then the value decreased slowly, because some leaves started to senesce during the later stage, especially the bottom leaves. The mulching plants grew faster than those with no mulching and the leaves developed well. Under traditional downslope cultivation plants grew more slowly, followed by plants under traditional contour cultivation. Mulching treatments brought forward the emergence of female flowers by 3-5 days (on ~90% of plants).

Figure 3.5.2 Effect of cultivation techniques on Green Leaf Index (GLAI) with the standard error bar during the 1999, 2000 and 2001 maize growing season: B -D, J -C, H -C+P, F -C+P+S and G -C+P+IS.

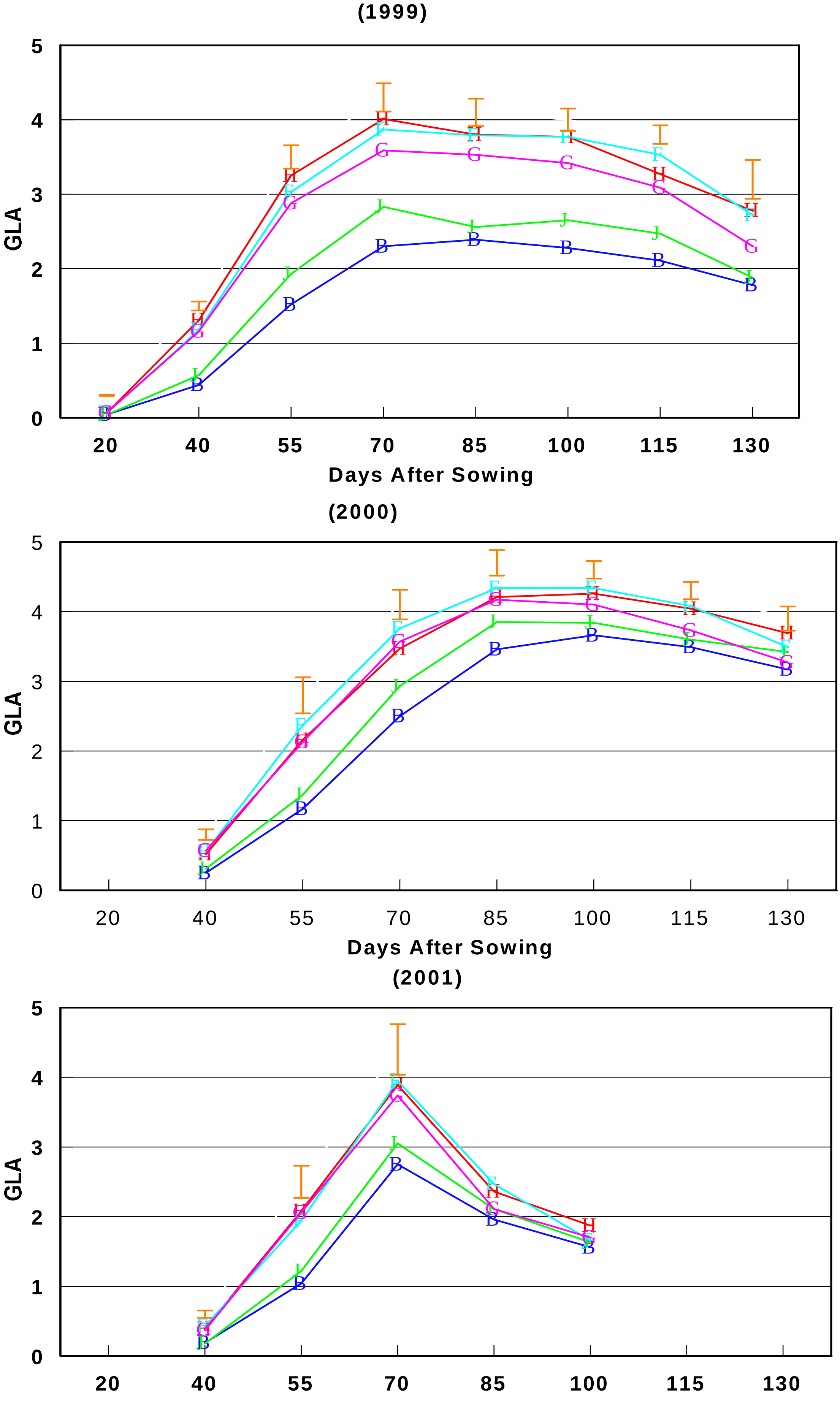


Table 3.5.2. Values of LAI (with F, P and LSD values) during the 1999, 2000 and 2001 crop growing season. Values are mean of 8 plants, analysed over 3 blocks (n = 3)

Years	DAS	F	P	LSD	Treatments				
					D	C	C+P	C+P+S	C+P+IS
1999	20	3.969	0.035	0.019	0.043a	0.040a	0.063b	0.057ab	0.067b
	40	81.313	<0.001	0.14	0.44a	0.57a	1.31c	1.18bc	1.16b
	55	45.385	<0.001	0.35	1.52a	1.93b	3.25d	3.03cd	2.88c
	70	29.843	<0.001	0.42	2.30a	2.83b	4.01c	3.87c	3.59c
	85	27.883	<0.001	0.41	2.39a	2.56a	3.80b	3.79b	3.53b
	100	40.894	<0.001	0.34	2.28a	2.65b	3.77d	3.77d	3.42c
	115	45.421	<0.001	0.27	2.11a	2.47b	3.27cd	3.53d	3.09c
	130	6.272	0.009	0.58	1.78a	1.88a	2.78b	2.72b	2.30ab
2000									
	40	8.285	0.003	0.17	0.25a	0.31a	0.52b	0.56b	0.57b
	55	8.403	0.003	0.58	1.17a	1.37a	2.16b	2.37b	2.13b
	70	11.712	0.001	0.48	2.50a	2.93a	3.47b	3.76b	3.57b
	85	7.459	0.005	0.41	3.46a	3.85ab	4.21bc	4.34c	4.17bc
	100	10.077	0.002	0.28	3.66a	3.84ab	4.26c	4.34c	4.10bc
	115	9.038	0.002	0.28	3.49a	3.60a	4.04b	4.08b	3.73a
	130	2.755	0.088	0.38	3.17	3.42	3.69	3.49	3.27
2001	40	10.240	<0.001	0.11	0.19a	0.18a	0.39b	0.43b	0.37b
	55	9.423	0.002	0.51	1.04a	1.22a	2.08b	1.94b	2.06b
	70	4.466	0.025	0.81	2.75a	3.05ab	3.89bc	3.95c	3.74bc
	85	1.741	0.217	-	1.96	2.11	2.36	2.47	2.11
	100	0.463	0.762	-	1.56	1.63	1.87	1.66	1.70

The results of GLAI and time measurements with repeated ANOVA measures also confirmed that treatments and time produced significant differences. GLAI was the dependent factor, treatment was the independent factor and time was the fixed factor.

Table 3.5.3a reports the 1999 season measure times ANOVA and Table 3.5.3b the significant difference between measurement times. Tables 3.5.4a and 3.5.5a report the 2000 and 2001 season measurement times ANOVA, respectively, and Tables 3.5.4b and 3.5.5b report the significant difference between measurement times in 2000 and 2001, respectively.

Table 3.5.3a. Plant LAI and measurement times by repeated ANOVA measures during the 1999 season

	F	P
Treatments	39.653	<0.01
Time	1145.595	<0.01
Treatments × Time interaction	9.137	<0.01

Table 3.5.3b. The significant difference for LAI times measurements with pairwise comparisons method during the 1999 season. Significant differences are denoted by * at p <0.05

	DAS20	DAS40	DAS55	DAS70	DAS85	DAS100	DAS115	DAS130
DAS 20	-	-0.88*	-2.47*	-3.27*	-3.16*	-3.12*	-2.84*	-2.24*
DAS 40		-	-1.59*	-2.39*	-2.29*	-2.25*	-1.96*	-1.36*
DAS 55			-	-0.80*	-0.69*	-0.65*	-0.37*	0.23*
DAS 70				-	0.11*	0.14*	0.43*	1.03*
DAS 85					-	0.04	0.32*	0.92*
DAS100						-	0.28*	0.89*
DAS115							-	0.60*
DAS130								-

Table 3.5.4a. GLAI and measurement times repeated ANOVA measures during the 2000 season

	F	P
Treatments	16.992	<0.01
Time	845.275	<0.01
Treatments × Time interaction	3.516	<0.01

Table 3.5.4b. The significant difference for LAI times measurements with pairwise comparisons method during the 2000 season. Significant differences are denoted by * at P <0.05

	DAS40	DAS55	DAS70	DAS85	DAS100	DAS115	DAS130
DAS 40	-	-1.40*	-2.80*	-3.56*	-3.60*	-3.34*	-2.96*
DAS 55		-	-1.40*	-2.16*	-2.20*	-1.94*	-1.56*
DAS 70			-	-0.76*	-0.80*	-0.54*	-0.16
DAS 85				-	-0.04	0.22	0.60*
DAS100					-	0.26*	0.64*
DAS115						-	0.38*
DAS130							-

Table 3.5.5a. GLAI and measurement times repeated ANOVA measures during the 2001 season

	F	P
Treatments	5.31	0.022
Time	252.400	<0.01
Treatments × Time interaction	5.094	<0.01

Table 3.5.5b. The significant difference for LAI times measurements with pairwise comparisons method during the 2001 season. Significant differences are denoted by * p<0.05

	DAS40	DAS55	DAS70	DAS85	DAS100
DAS 40	-	-1.36*	-3.16*	-1.89*	-1.37*
DAS 55		-	-1.81*	-0.53*	-0.02
DAS 70			-	1.27*	1.79*
DAS 85				-	0.52*
DAS100					-

Plant stem girth

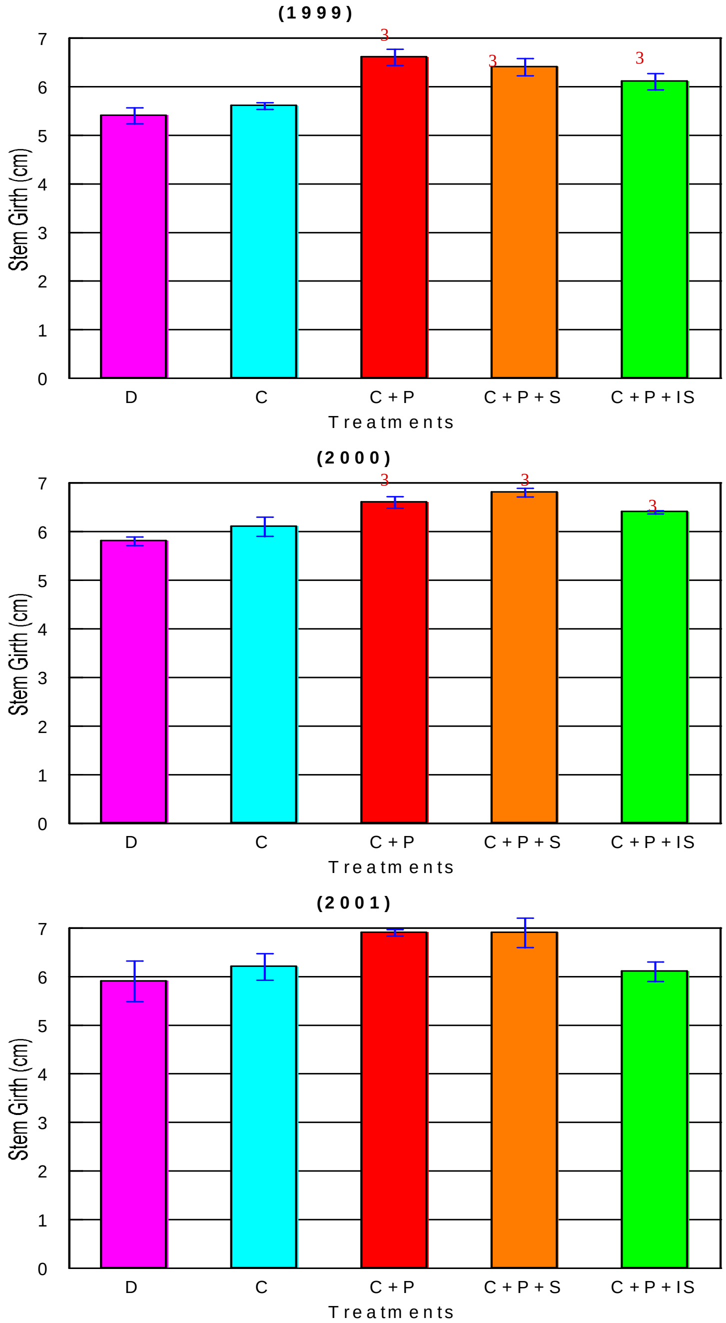
After harvest, plant stem girth was measured between the third and fourth nodes on the stem. Stem girth on the 1999, 2000 and 2001 seasons are presented in Figure 3.5.3. In 1999 and 2000, significant treatments effects were found between the mulch treatments and no mulch treatments (in 1999, F = 24.03, P<0.01, LSD = 0.49 cm and in 2000, F = 9.781, P<0.01, LSD = 0.38 cm). In 1999, C+P treatment produced greatest stem girth, followed by C+P+S and then C+P+IS treatments. The least stem girth was on D treatment, then followed by the C treatment.

In 2000, C+P+S produced the maximum stem girth, then the C+P and C+P+IS treatments. Less stem girth was also found on the D treatment and C treatment was in the middle. In 2001, there were no significant differences among the treatments (F =

2.741, P = 0.089), the heavy hail during the maize flowering and silk stage probably influenced this result. C+P and C+P+IS treatments still produced higher stem girth than other treatments. The lowest stem girth was still on the D treatment.

In summary, over three seasons the stem girth under the polythene mulch treatments was greater than under the no mulch treatments, C+P and C+P+S treatments consistently maintained stable and high value. The lowest stem girth was on D.

Figure 3.5.3. Effect of cultivation techniques on the maize stem girth of the harvested eight sample plants with standard error bar in 199, 2000 and 2001. Stars denote significant differences(p<0.05).



3.5.2 Maize harvest components

Yields from the eight samples plants per plot

Yields from the samples plants over three seasons are shown in Figure 3.5.4 with full analysis and % differences shown in Table 3.5.6. The mulch treatments increased crop yields from 38.8-60.8% in terms of grains weights compared with treatment D and the yield of treatment D was the lowest. Contour cultivation (C) yield was also low, but it had 18.1% more grain yield than treatment D. The highest yield was on C+P, the increased percentage was 60.8% compared with treatment D. Then followed C+P+S, the increase percentage was 48.9% and C+P+S treatment increased yield by 38.8%. In 1999, the highest yield was achieved with the C+P treatment; in 2000, it was C+P+S and in 2001, it was again C+P+S. However, there were no significant differences between all three mulched treatments.

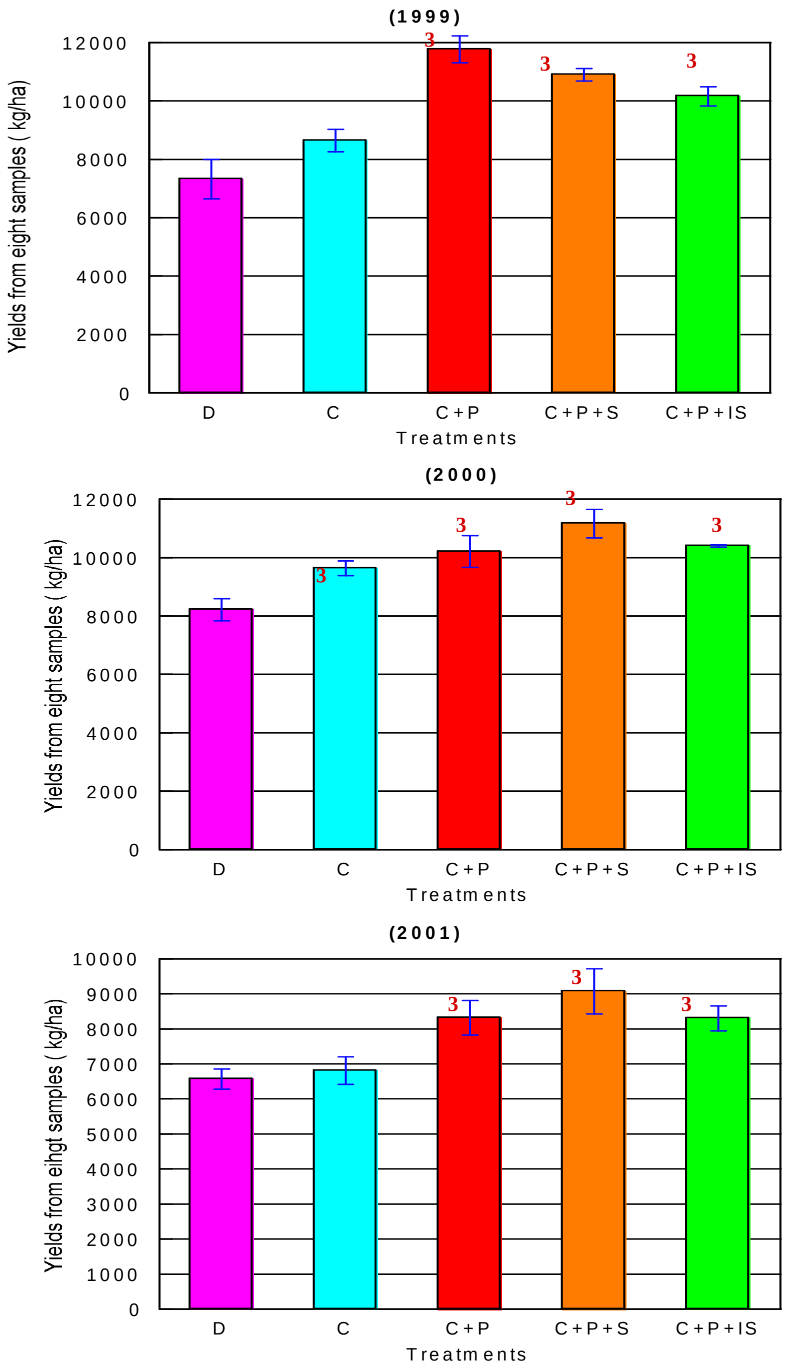
The 2000 grain yield data did show significant differences between treatments (Table 3.5.6). The C+P+S treatments produced greater yield, followed by C+P+IS and then C+P treatments. Treatment D had the lowest yield. Contour cultivation (C) yield, in this calculation method, increased grain yield by 17.3% compared with treatment D.

Table 3.5.6. Grain yields (tonnes/ha, corrected to 13% moisture) from eight sampled plants analysed over 3 blocks over three seasons, show % increase and F and P value. Different letters denote significant differences (n = 3)

Treatments	year						
	1999	Increasing % vs. D	2000	Increasing % vs. D	2001	Increasing % vs. D	Mean yield over three years
D	7.34a	0	8.21a	0	6.57a	0	7.37
C	8.64a	18.1	9.63b	17.3	6.81a	3.7	8.36
1	11.87b	60.8	10.20bc	24.2	8.32b	26.6	10.10
C+P+S	10.89b	48.9	11.16c	35.9	9.07b	38.1	10.37
C+P+IS	10.16b	38.8	10.40bc	26.6	8.30b	26.4	9.62
F value	16.5	-	8.11	-	5.65	-	
P Value	<0.01	-	<0.01	-	<0.05	-	
LSD	1.62 t	-	1.22 t	-	1.43 t	-	

In 2001, heavy hail influenced final yields, which was reduced in all plots. Within this year, the grain yield data (corrected to 13% moisture) showed significant differences between treatments (Table 3.5.6). The C+P+S treatments produced greater yield, followed by C+P+IS and the C+P treatments. The yield of treatment D was lowest, with no difference between it and treatment C, but the yield under C increased by 3.7% compared with treatment D.

Figure 3.5.4 Effect of cultivation techniques on the yields with 13% moisture correction from the plots, with standard error bar, in 1999, 2000 and 2001. The star denotes significant differences ($p<0.05$).



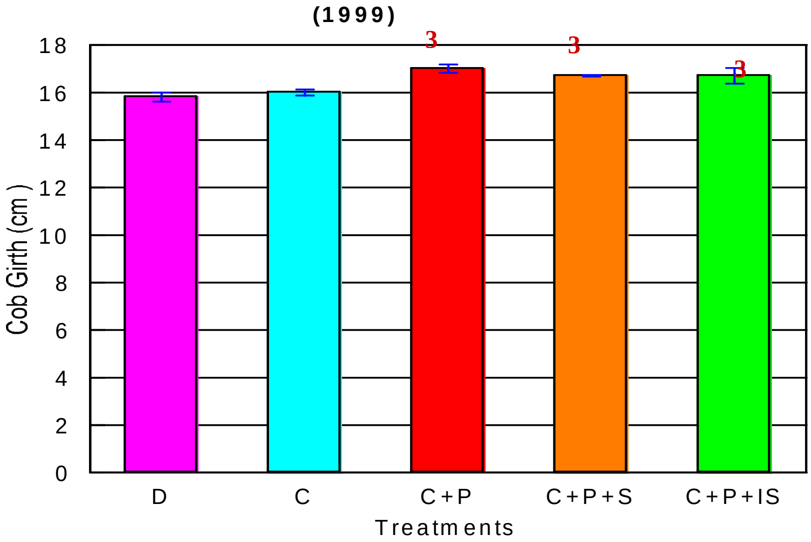
Cob girth, cob length and 1000 grains weight

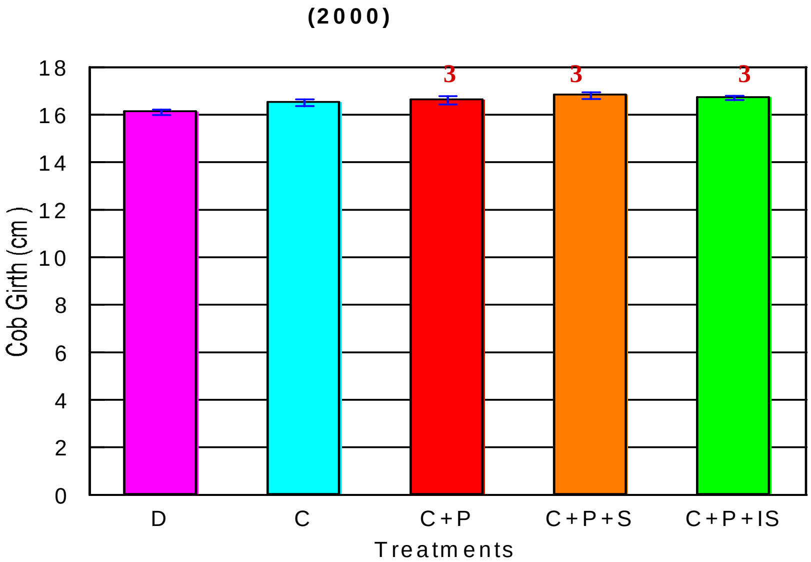
In addition to measuring grain yield, the other harvest components were measured on all sample plants. Figure 3.5.5 shows cob girth; Figure 3.5.6 shows cob length and Figure 3.5.7 shows 1000 grain weight in 1999, 2000 and 2001, respectively. Table 3.5.7 reports other harvest parameters in 1999, 2000 and 2001 (with F, P and LSD values), respectively. All the data in this section were subjected to analysis by one way ANOVA.

Over three experimental years, cob girth in 1999 and 2000 showed significant treatment effects. In 1999, C+P produced longer cob girth, followed by C+P+S and then C+P+IS, but there was no significant difference between them. However there was a significant difference between D and C treatments, with the smaller cob girth produced by D. In 2000, C+P+S produced greatest cob girth, followed by C+P and then C+P+IS. D still produced the shortest cob girth. In 2001, though there were no significant treatment effects, the difference was still observed between them, the trends were similar to 2000 in terms of C+P+S >C+P >C+P+IS >C >D.

For cob length, different patterns were found. In 1999, though there were no significant treatment effects. In 2000 and 2001, D produced the shortest cobs and in 2000 significant differences were found between D and other treatments ($F = 5.756$, $P = 0.011$, LSD = 0.91 cm). For 1000 grain weight, in 1999, there were no significant treatment effects, while in 2000 and 2001 the mulch treatments produced higher weight.

Figure 3.5.5 Effect of cultivation techniques on cob girth of the harvested eight sample plants with standard error bar in 1999, 2000 and 2001. the star denotes significant differences(p<0.05).





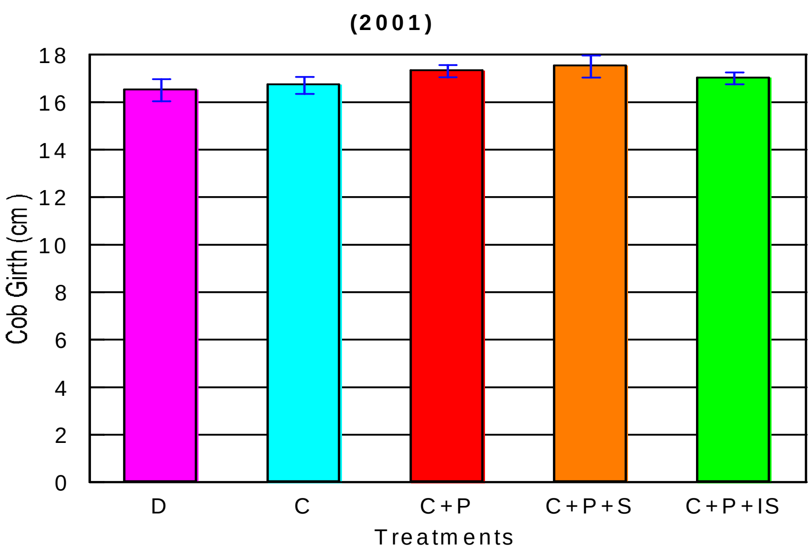


Figure 3.5.6. Effect of cultivation techniques on the fresh cob length of the harvested eight sample plants, with standard error bar in 1999, 2000 and 200.The star denotes significant differences (p<0.05).

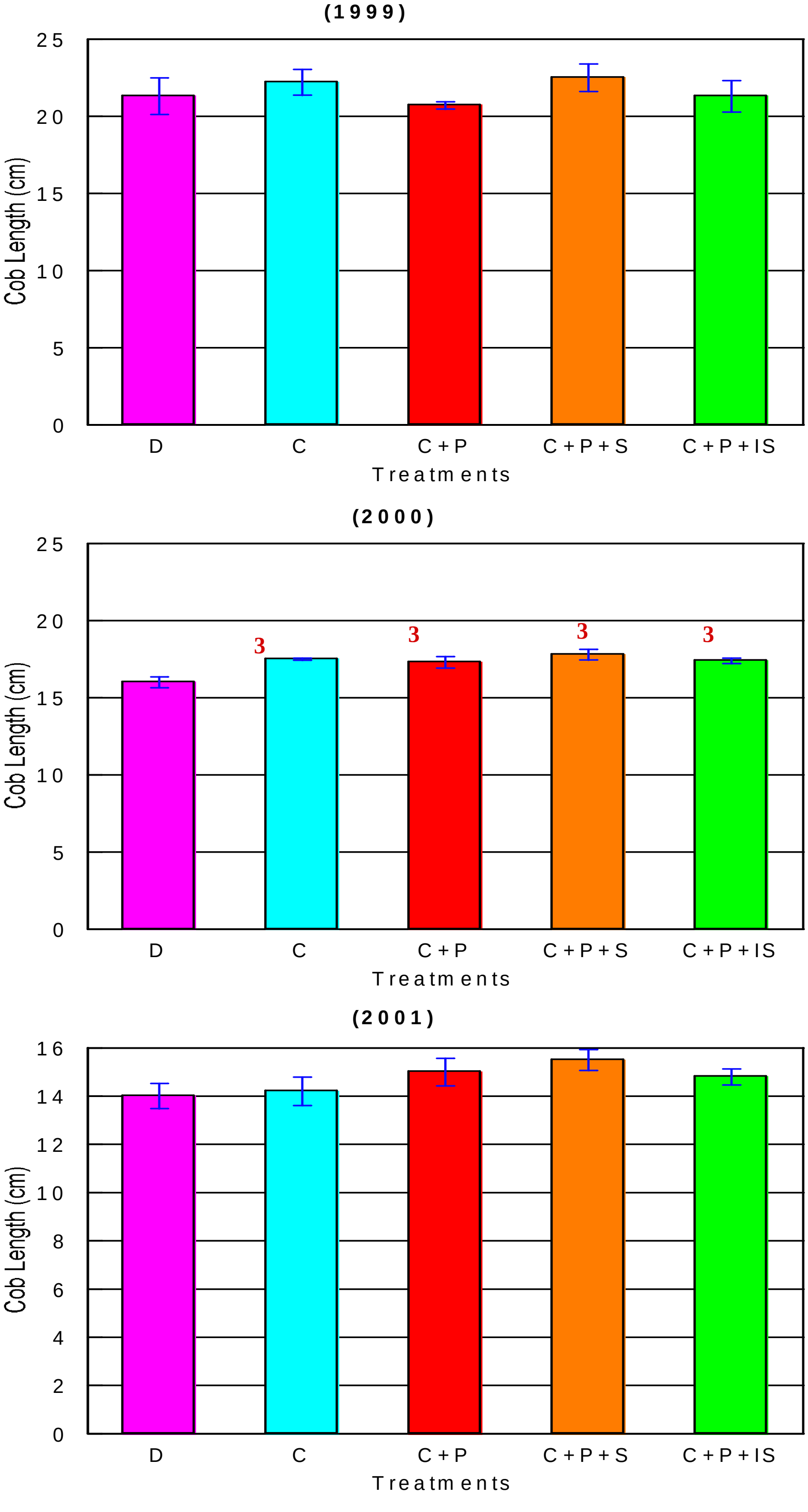
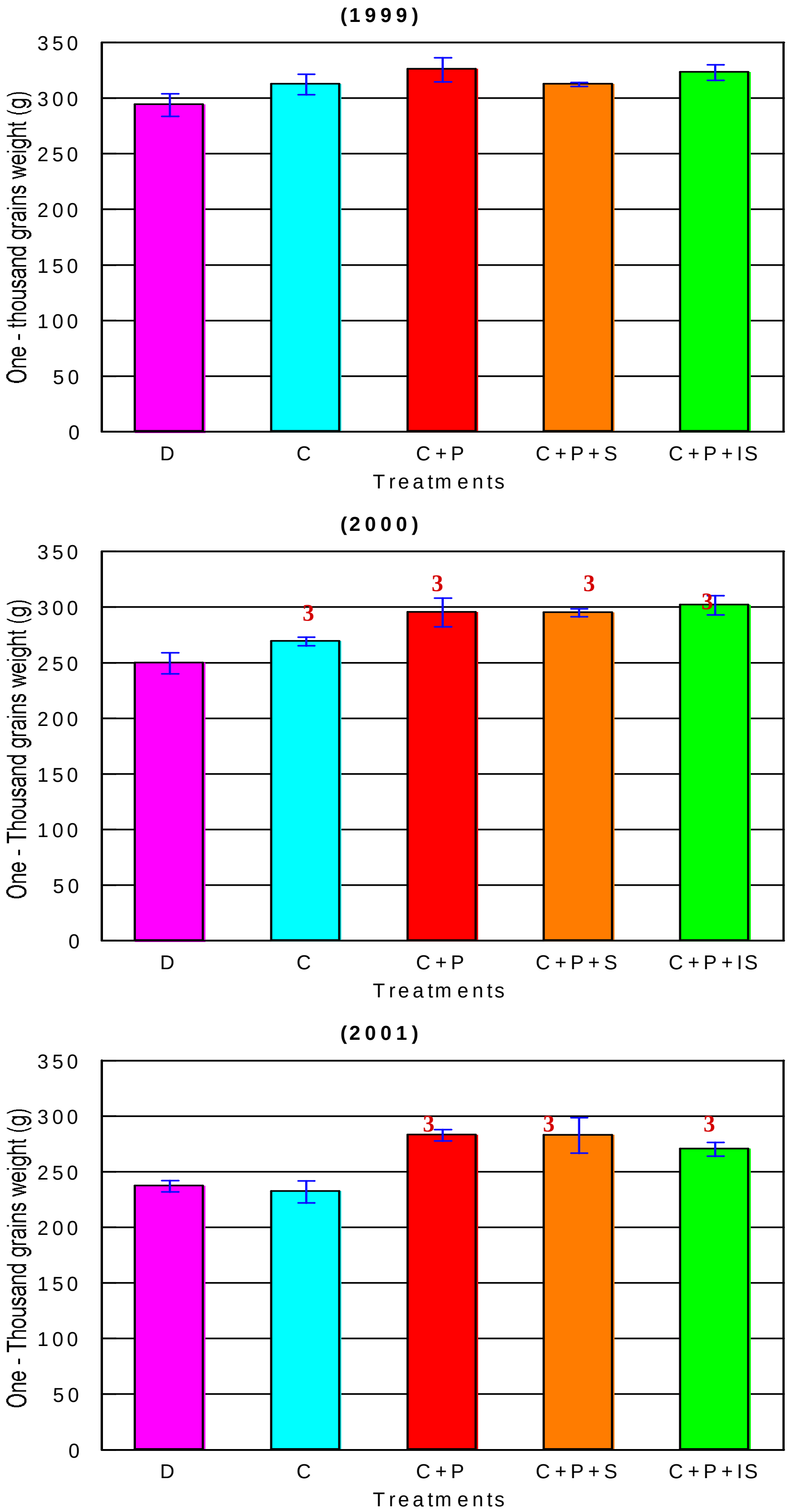


Figure 3.5.7. Effect of cultivation techniques on the 1000 grain weight of the harvested eight sample plants with standard error bar in 1999, 2000 and 2001.The star denotes significant differences (p<0.05).



Other harvest components

More detailed analysis of yield components is presented in Tables 3.5.7 over three years, which showed notable treatments effects. The use of polythene mulch (C+P) resulted in the best performance in terms of yield components compared with other treatments. The C+P+S and intercropping with polythene mulch (C+P+IS) treatments also increased yield components. Significant differences were found between the mulching treatments and no-mulching treatments. Generally, the mulching treatments were better than no mulching treatments, followed by the traditional contour cultivation treatment. Traditional downslope cultivation was least productive.

Interpreting the treatment effects between the three seasons, more marked effects were found in 1999. C+P had higher fresh and dry cob, stem and leaves weight. Thus, C+P produced more biomass than other treatments, it also had a higher cob rows and grains on the row, and was then followed by C+P+S and C+P+IS treatments. Traditional downslope cultivation treatment (D) produced lower cob, stem and leaves weight and also fewer grains on the cob row than other treatments. C productivity was higher than D. There were significant differences between them for grain number of every two rows and weight of dry stem + leaf (Table 3.5.7). These differences were associated with much higher yields for all mulch treatments. In 2000 and 2001, except for fresh and dry cob weight, dry grain weight, there were no significant effects. Yield responses were also lower in these years.

Table 3.5.7. Maize harvest component analysis of the eight sample plants during the 1999-2001 crop growing seasons. The data have been analysed by AVOVA (P<0.05), different letters denote significant differences (n = 3)

1999								
Items	F	P	LSD	D	C	C+P	C+P+S	C+P+IS
Fresh Cob weight (g/plant)	12.64	<0.001	38.90 g	243.9a	278.2ab	349.1d	341.4cd	305.8bc
Fresh Stem + Leaf weight (g/plant)	9.58	<0.001	70.93 g	243.4a	284.9ab	400.7c	399.2c	320.6b
Dry Cob weight (g/plant)	15.37	<0.001	24.21 g	129.9a	152.5a	203.0b	193.7b	178.5b
Dry Stem + Leaf weight (g/plant)	31.49	<0.001	12.84 g	73.6a	88.8b	127.2d	123.8d	105.2c
Dry Grain weight (g/plant)	16.42	<0.001	20.21 g	106.7a	126.0a	171.6c	158.9bc	148.2b
Grain No. every two rows	10.85	<0.001	5	59a	66.3b	70.7bc	72c	69bc
No. of rows per cob	14.55	<0.001	1.21	11.7a	12.0a	15.2c	15.2c	13.7b
2000								
Items	F	P	LSD	D	C	C+P	C+P+S	C+P+IS
Fresh Cob weight (g/plant)	6. 58	<0.01	32. 58 g	278.5a	315.9b	320.8b	348.1b	337.0b
Fresh Stem + Leaf weight (g/plant)	2. 47	0. 113	–	331.6	399.6	413.5	405.4	375
Dry Cob weight (g/plant)	7. 53	<0.01	21. 23 g	148.2a	172.1b	180.5bc	197.8c	185.2bc
Dry Stem + Leaf weight (g/plant)	2. 27	0. 134	–	103.7	122.8	128.7	132.2	122.9
Dry Grain weight (g/plant)	8. 11	<0.01	17. 77 g	119.8a	140.5b	148.8bc	162.8c	151.7bc
Grain No. every two rows	3. 07	0. 07	–	66.6	72.5	72.5	73.2	68.9
No. of rows per cob	0. 10	0.98	–	14.5	14.6	14.3	14.4	14.6
2001								
Items	F	P	LSD	D	C	C+P	C+P+S	C+P+IS
Fresh Cob weight (g/plant)	2. 89	0.08	–	244.6	252.7	287.8	311.7	287.3
Fresh Stem + Leaf weight (g/plant)	1. 44	0. 29	–	407.8	426.9	504.1	518.5	458.1
Dry Cob weight (g/plant)	6. 49	<0.01	23. 29 g	124.3a	126.2a	153.7b	167.4b	152.7b
Dry Stem + Leaf weight (g/plant)	1. 21	0. 37	–	89.3	96.7	111.6	110.8	115.5
Dry Grain weight (g/plant)	5. 67	<0.05	20. 78 g	95.8a	99.4a	121.3b	132.3b	121.1b
Grain No. every two rows	3. 26	0. 06	–	55	56.3	59.7	61.7	59.3
No. of rows per cob	0. 69	0. 62	–	14.9	15.6	15.1	15.5	15.9

3.5.3 Maize yields from the plot measurements

This second method of yield determination was used in addition to sampled plants to assess overall plot yield in a way similar to that used by the catchment farmers. Plot yields over three seasons are shown in Figures 3.5.8, with full analysis and % difference in Table 3.5.8. In 1999, mulch treatments increased grain weight from 40.3 to 54.0% compared with treatment D. The yield of treatment D was the lowest. Contour cultivation (C) treatment yield was also low, but increased 11.2% compared with treatment D. The highest yield was on C+P, where the percentage increase was 54.0% compared with treatment D, and was then followed by C+P+S, where the percentage increase was 48.7%. C+P+S treatment also increased yield by 40.3%.

The 2000 grain yield data showed a similar trend, but the differences were not significant, unlike the data from the sampled plants. Grain weight under the mulch treatments appeared to be higher, increasing up 24.0% compared with D. Treatment D yield was the lowest. Contour cultivation (C) yield in this year increased by 12.7% compared with D.

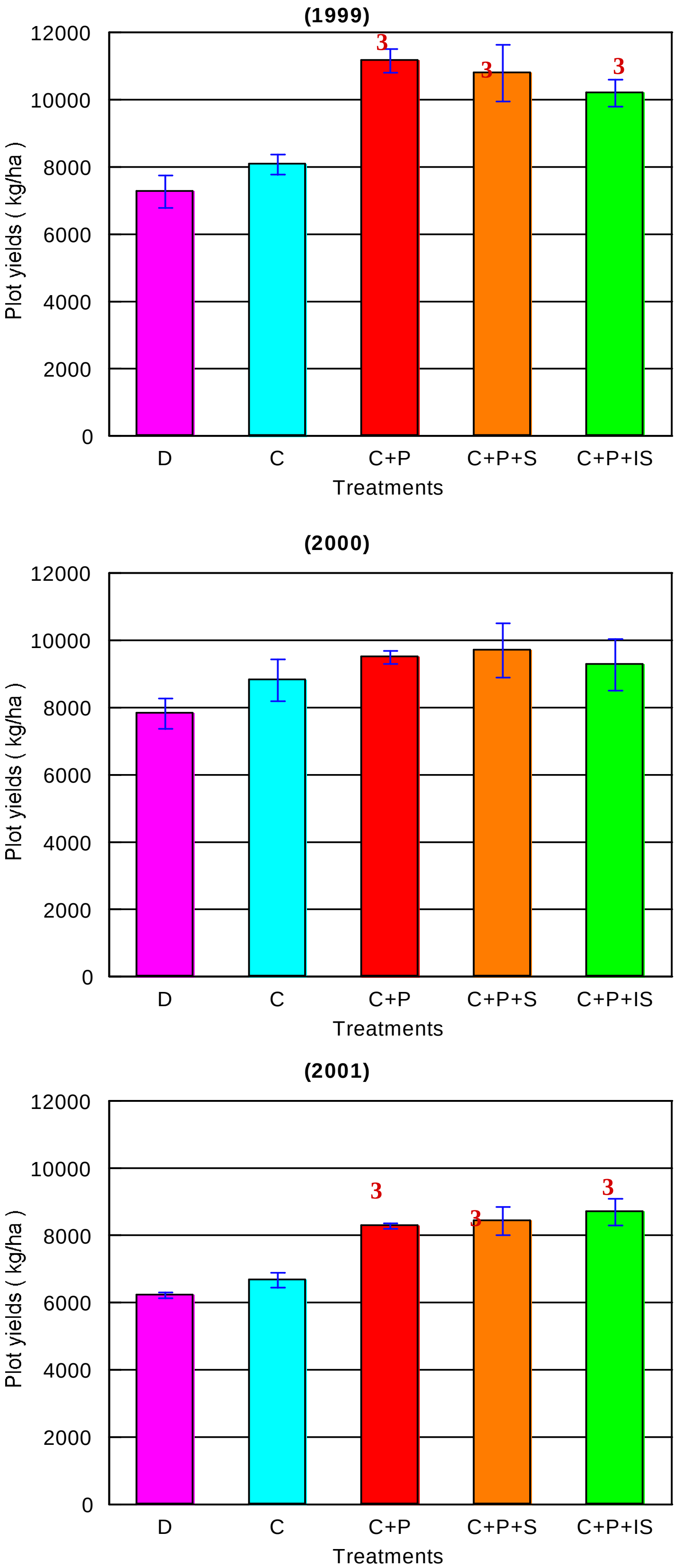
Table 3.5.8. Grain weight (t/ha, corrected to 13% moisture)) from plot over three seasons with F and P values. Different letters denote significant differences

Treatments	Year					
	1999	Increasing % vs. D	2000	Increasing % vs. D	2001	Increasing % vs. D
D	7.26a	0	7.82	0	6.21a	0
C	8.08a	11.2	8.81	12.7	6.66a	7.2
C+P	11.19b	54.0	9.49	21.4	8.27b	33.2
C+P+S	10.80b	48.7	9.70	24.0	8.42b	35.5
C+P+IS	10.19b	40.3	9.27	18.6	8.69b	39.8
F	37.46	-	1.49	-	16.17	-
P	<0.01	-	0.28	-	<0.01	-
LSD	1.39 t	-	-	-	0.88 t	-

In 2001, though the heavy hail storm decreased the final grain yield on all treatments, within the year the grain yield data still showed significant differences between treatments (Table 3.5.8). The C+P+IS treatment produced a greater yield, followed by

C+P+S and C+P treatments, where the yield increase was 39.8, 35.5 and 33.2%, respectively. The yield of treatment D was least. Contour cultivation (C) appeared to increase yield by 7.2% compared to D.

Figure 3.5.8. Effect of cultivation techniques on the yields with 13% moisture correction from the plots, with standard error bar in 1999, 2000 and 2001. The star denotes significant differences($p<0.05$).



Plot Stem and leaf yields

After harvest, total fresh stem and leaf was determined for each plot on-site. Three seasons results are shown in Figures 3.5.9. In 1999, significant treatments effects were found. C+P+S produced greater fresh leaf + stem, followed by C+P treatment, with no significant difference between them. Although C+P+IS appeared to produce more fresh leaf + stem than C and D treatments, there was no significant difference. In 2000, as with plot yields, there was a trend of increasing biomass in the mulched treatments, but no significant difference.

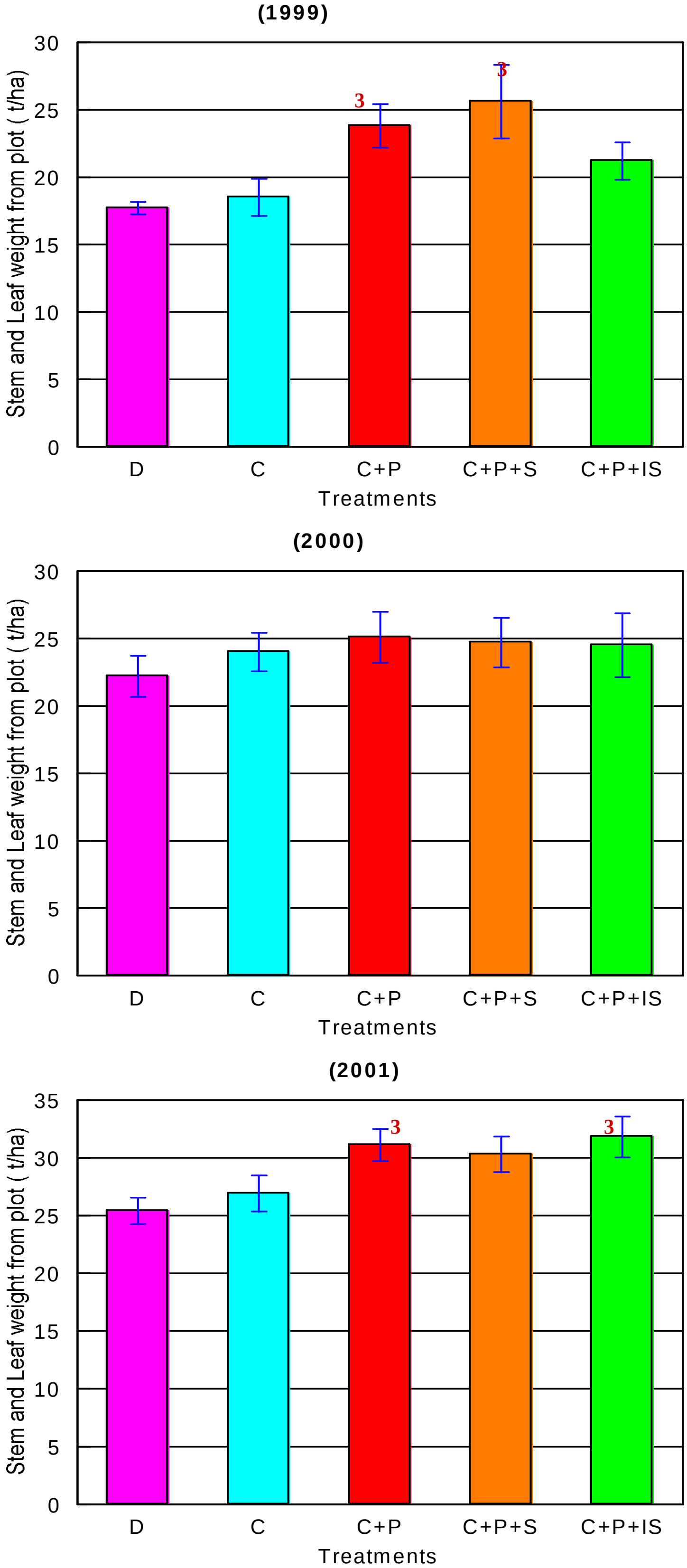
In 2001, most treatments followed the similar trends with 1999, but the maximum fresh leaf + stem was under C+P+IS treatment, then followed by C+P treatment, but there was no significant difference between them. C+P+S and C treatments produced more fresh leaf + stem than D treatment, but no significant difference was found.

For scientific purposes, dry weight determinations were required, as the stem and leaf weights were strongly affected by rainfall patterns. Therefore, conversion of fresh stem plus leaf to dry matter weight was necessary. To calculate dry stem and leaf weight from the plot, the sample plants was used to estimate the ratio of dry stem plus leaf and fresh stem plus leaf and then this ratio was used to multiply the total plot fresh stem and leaf to give the dry stem and leaf from the plot (Table 3.5.9).

Table 3.5.9. Total dry stem plus leaf from plots over three experimental years (t/ha)

Treatment Year	F	P	LSD (t)	D	C	C+P	C+P+S	C+P+IS
1999	4.466	<0.05	1.68	5.3a	5.8a	7.6b	7.9b	7.0ab
2000	0.676	0.624	-	6.9	7.4	7.8	8.0	8.0
2001	7.053	<0.01	1.09	5.6a	6.1ab	6.9b	6.5ab	8.0c

Figure 3.5.9. Effect of cultivation techniques on the fresh stem and leaf weight from the plots with standard error bar in 1999, 2000 and 2001. The star denotes significant differences (p<0.05).



Soybean growth and yield

For the C+P+IS treatment, the growth and yield of the soybean plants were measured each season (Table 3.5.10). The soybean was planted and intercropped with maize in wide row spacing. The growth period for soybean is shorter than maize. During the early stage, it grows rapidly and increases the ground cover, thus protecting the soil surface from erosion.

Table 3.5.10. Soybean growth and yields over three years (1999-2001) (n = 24)

Year	DAS	Leaf number	Height (cm)	Branch number	Pods number	Dried grain weight (kg/ha)	Dried stem weight (kg/ha)
1999	20	2	12				
	40	4	20				
	60	8.8	51.6	0.71	5.5		
	80	10.1	55.2	1.8	13.3		
	115					469.5	643.5
2000	55	3.8	33.0	1			
	70	11.5	51.8	1.8			
	85	11.1	55.3	2.4			
	98	9.6	57.6	2.8			
	112		67.7	2.1	2.1	-	-
2001	55	4.0	21.5				
	70	6.0	36.8				
	88	7.1	54.7				
	100	5.0	52.0		6.2		
	115					539.2	1211.2

In 2000, the pods failed to set properly and virtually no grain developed. No crop was harvested. It was probably that particularly heavy rainfall during pollination adversely affected flower fertilization. Vegetative growth was correspondingly greater than in the other seasons.

3.5 Evaluation of economic benefits of the treatments

Analysis of net returns can assist interpretation of the effects of different treatments in terms of economic benefits. Table 3.6 shows the input and output of the different treatments in 1999, 2000 and 2001.

In 1999, the greater net return was achieved by C+P, even when taking labour cost into consideration. The final net return was 3980.9 Yuan /ha (8 Yuan ≅ 1$ 10/1999). The output of C+P+IS was from both maize and soybean. This year it produced the greatest outputs among the treatments, but the higher inputs made the final net return rank second, at 3634.9 Yuan/ha. Then followed C+P+S, the materials input of this treatment was ranked second and final net return was 3282.9 Yuan/ha. Although the inputs and labour cost of D was the lowest, the net return was also the lowest. C needs more labour, but the net return was 322.0 Yuan/ha more than D and the input investment was the same as D, the only change was just the cultivation direction.

In 2000, different patterns were observed among the treatments. The highest outputs were with C+P+S, then C+P and C+P+IS. D had the lowest output. But the net return was similar to 1999 and C+P still produced the greatest net return. C+P+IS in this year had the lowest net income, because of the failure of the soybean harvest, so there was no compensation for the higher material input. The final order for the net return was C+P>C>C+P+S>D>C+P+IS.

In 2001, heavy hail on 9 August influenced the level of the final output, but the difference between the treatments were still observed. The outputs of this year were C+P+IS>C+P+S>C+P>C>D, and the final net return were C+P+IS>C+P >C+P+S>C>D. In all three years, the higher costs of the straw mulch did not give a higher net return because the yield responses were not sufficiently marked.

Table 3.6. Return and the cost of different cultivation methods in 1999, 2000 and 2001

Year	Treatments	Outputs (Yuan/ha)	Inputs (Yuan/ha)	Net return excluding labour (Yuan/ha)	Labour cost (Yuan/ha)	Net return including labour (Yuan/ha)
1999	D	5810	1417	4393	2715	1678
	C	6462	1417	5045	3045	2000
	C+P	8949	1953	6996	3015	3981
	C+P+S	8641	2253	6388	3105	3283
	C+P+IS	9093	2353	6740	3105	3635
2000						
	D	6256	1417	4839	2715	2127
	C	7051	1417	5634	3045	2589
	C+P	7594	1953	5641	3015	2623
	C+P+S	7760	2253	5507	3105	2402
	C+P+IS	7417	2353	5064	3105	1959
2001						
	D	4971	1417	3554	2715	839
	C	5329	1417	3911	3045	866
	C+P	6620	1953	4666	3015	1651
	C+P+S	6738	2253	4485	3105	1380
	C+P+IS	8027	2353	5674	3105	2569
Mean over three years						
	D	5679	1417	4262	2715	1547
	C	6281	1417	4863	3045	1818
	C+P	7721	1953	5768	3015	2753
	C+P+S	7713	2253	5460	3105	2355
	C+P+IS	8179	2353	5826	3105	2721

In summary, the results from three years showed that usually C+P produced the highest net return. The highest input for the C+P+IS strongly rely on both maize and soybean, if both crops had a good harvest, it would achieve the highest return. But if one crop failed, the final net return was sharply reduced. C+P+S settled in the middle and D usually had the lowest return. C produced a better net return than D.

3.7 Analysis of relationship between maize yield and other factors

Correlation between crop yields and crop growth

Crop yield depends on crop development and the crop stem girth, plant height and GLAD data were analysed to explore these relationships. Figure 3.7.1 shows the relationship curve between yield and stem girth for three years. Stem girth was the mean of the final 8 samples stem girths. In 1999 (A) the correlation was significant at $P < 0.01$ ($r = 0.775$, $n = 8$). In 2000 (B) and 2001 (C) the relationship between them was not significant.

Maize plants grow very fast during the early crop stage and reaches maximum height well before full crop development, then it develops to its maximum height (Figure 3.7.2). Results from three seasons showed that the crop achieved its maximum height ~85 DAS. So the daily plant growth to maximum height was calculated and the correlations between yield and these data were evaluated. Considering thee data from three years, the relationship between yield and daily plant growth was strong. In 1999 (A) and 2001 (C) the correlation between them was significant at $P < 0.01$ and in 2000 was significant at $P < 0.05$.

GLAD showed strong relationship with crop yield (Figure 3.7.3). In 1999 (A) and 2001 (C) the correlation between them was significant at $P < 0.01$ level and in 2000, was significant at $P < 0.05$. Considering all these three parameters, it was probable to predict the final yield using simple regression equations (Table 3.7.1).

Table 3.7.1. Yield was predicted by the equation: yield = Estimate 1 * daily plant growth (DPG) + Estimate 2 * GLAD + Estimate 3* Final stem girth (FSG) + intercept

Year	R^2	P	Regression coefficient							
			Daily plant growth		GLAD		Final stem girth		Intercept	
			Estimate 1	SE	Estimate 2	SE	Estimate 3	SE	Estimate	SE
1999	0.883	<0.01	2.15	3.53	0.0227	0.02	-0.0683	0.72	-1.19	7.48
2000	0.500	<0.05	1.06	2.70	0.0327	0.02	-1.63	1.21	7.39	6.29
2001	0.808	<0.01	4.61	2.64	0.0267	0.02	-0.48	0.34	-5.66	6.10

Figure 3.7.1 The regression of yield and final stem girth for the three years of cropping seasons

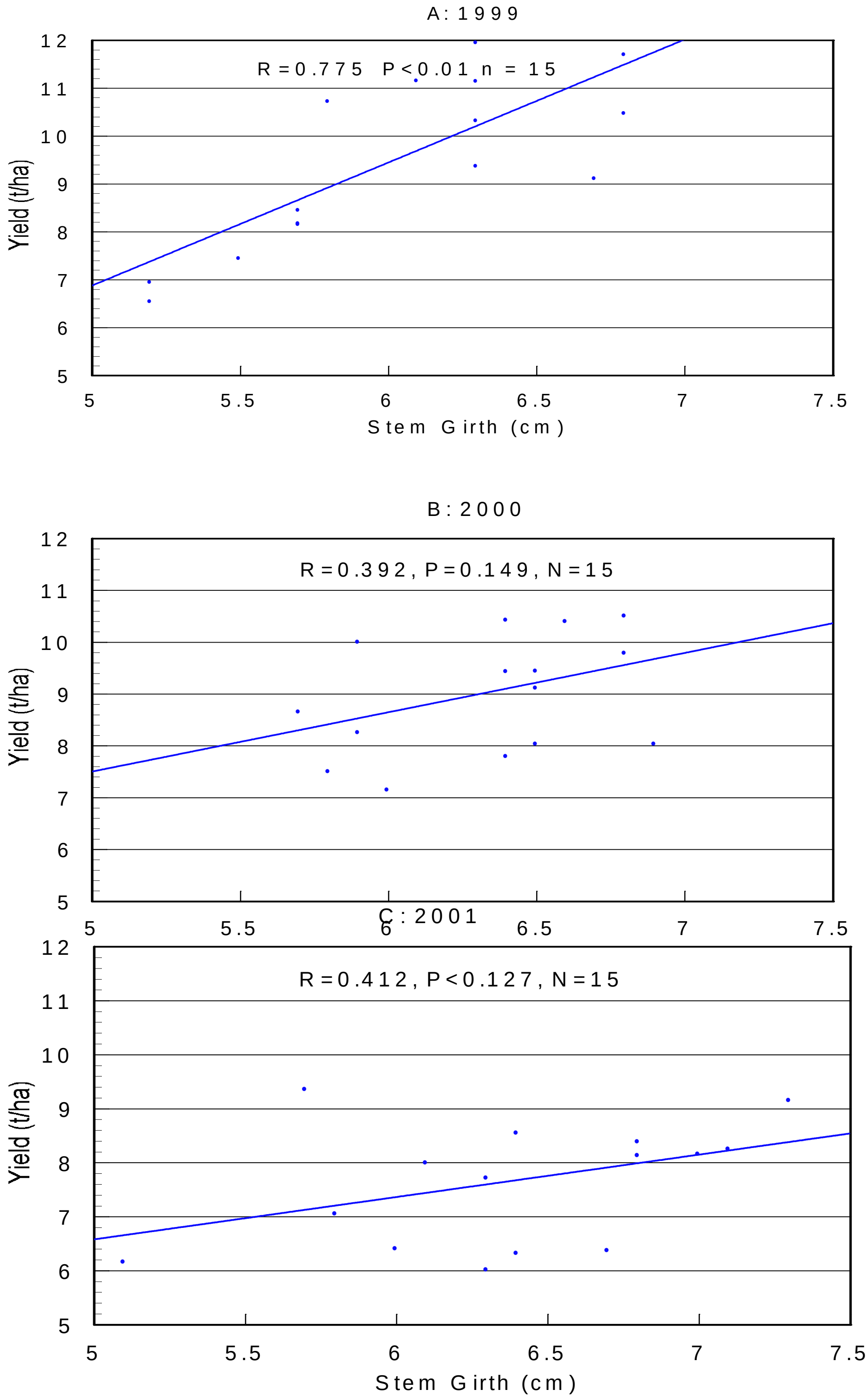


Figure3.7.2 The regression of yield and daily plant height before 85 DAS for the three years of cropping seasons

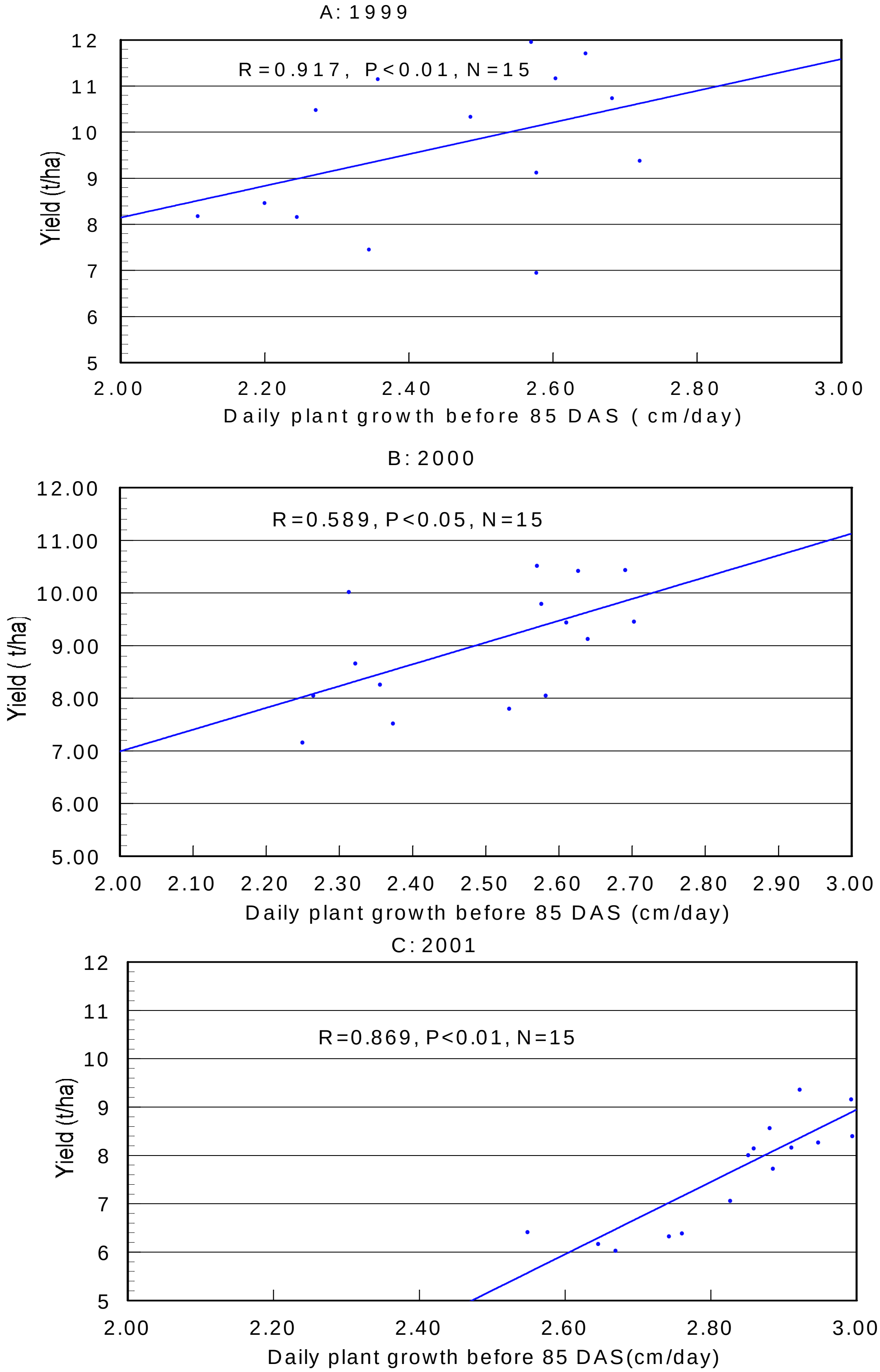
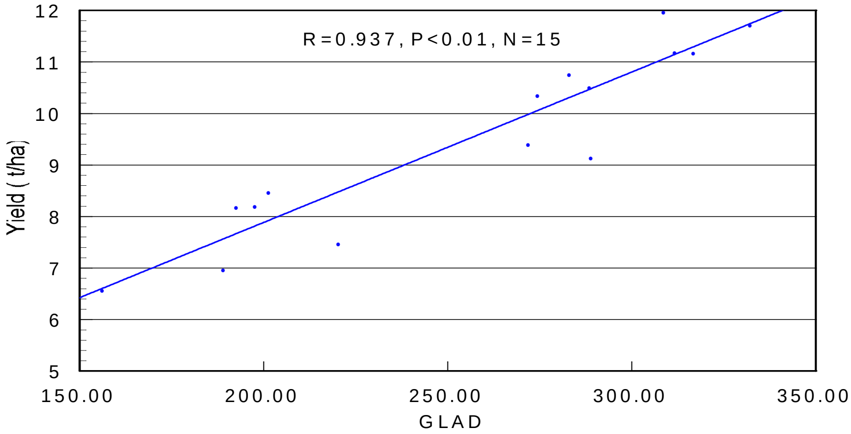
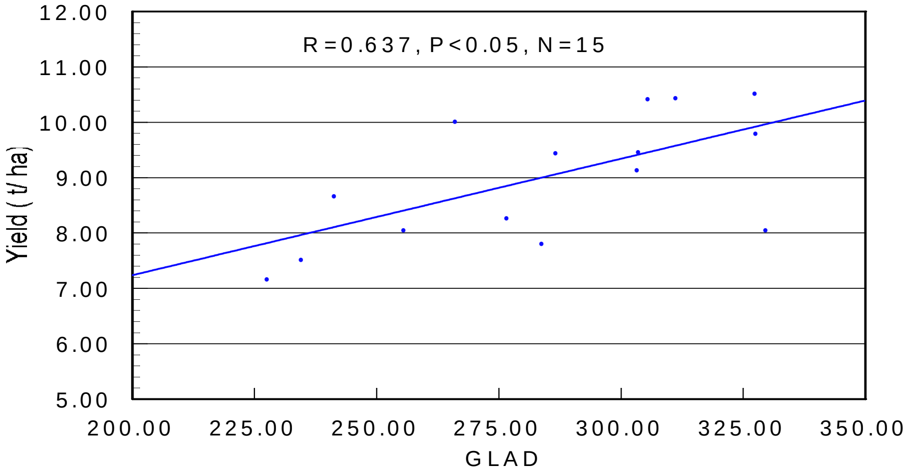


Figure3.7.3 The regression of yield and GLAD for the three years of cropping seasons. Note that each X-axis is different

A: 1999



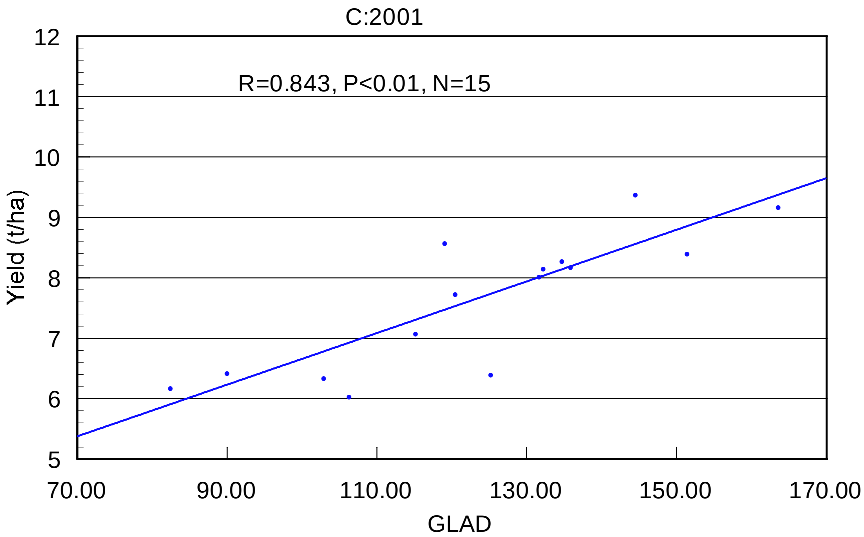
B:2000



3.8 Winter wheat

After the maize harvests in both 1999 and 2000, plants were taken to the laboratory to measure yield and other harvest parameters (total biomass, 1000-grains weight, grain weight, plant height and spike length).

During 2000/2001 wheat growing season, soil temperature and soil moisture were also recorded. Figure 3.8.1 presents soil temperature at both 1 and 5 cm depth and Figure 3.8.2 presents soil moisture during this season.



Soil temperature at both soil depths had the same pattern: at the beginning, soil temperature was quite high and then decreased slowly. At the later stage, it warmed up again. Soil temperature at 5 cm depth was lower than at 1 cm depth, usually the value was <15°C. Soil moisture during this season was very low. The usual condition for this season in this area was to be dry and cold, rather than hot and wet as during summer.

The harvest

Wheat yields and other components are shown in Tables 3.8.1 and 3.8.2. The yield of straw was very valuable as a source of mulch for the summer crop. The wheat grain harvest also contributed to the local diet, where rice is generally the staple food. Comparing the yields in the two seasons, the yield from 1999/2000 was higher than 20000/2001. The results showed that previous crop treatments had no significant influence on winter wheat. This was the main purpose to see if there was any carry over of treatment effects between seasons.

Figure 3.8.1 Soil temperature at 1 cm and 5 cm soil depths during 2000/2001 wheat growing season.

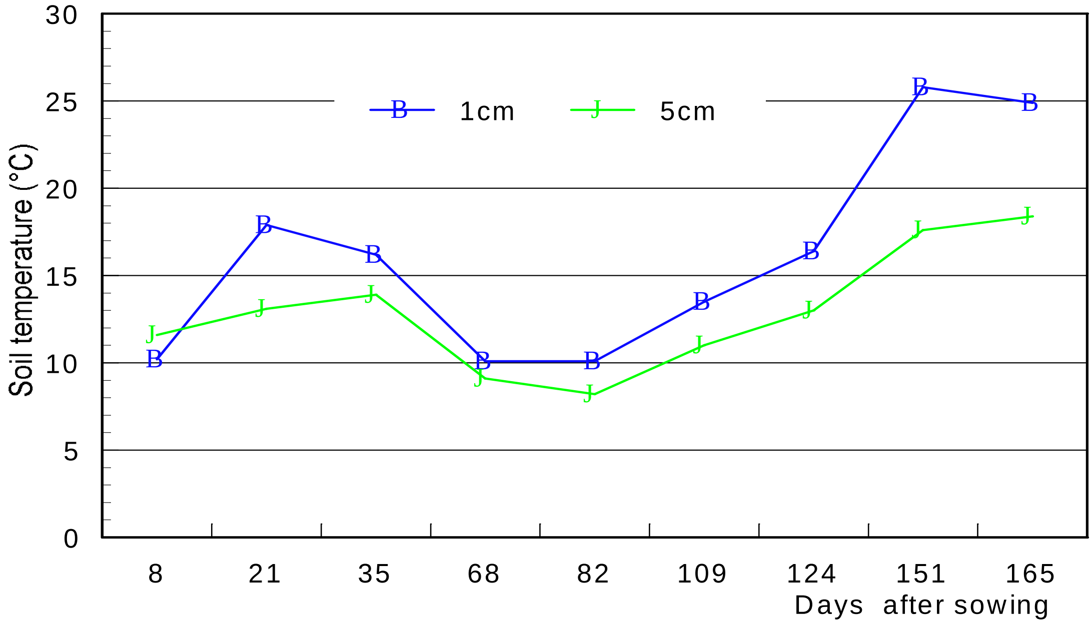


Figure3.8.2 Soil moisture during 2000/2001 wheat growing season.

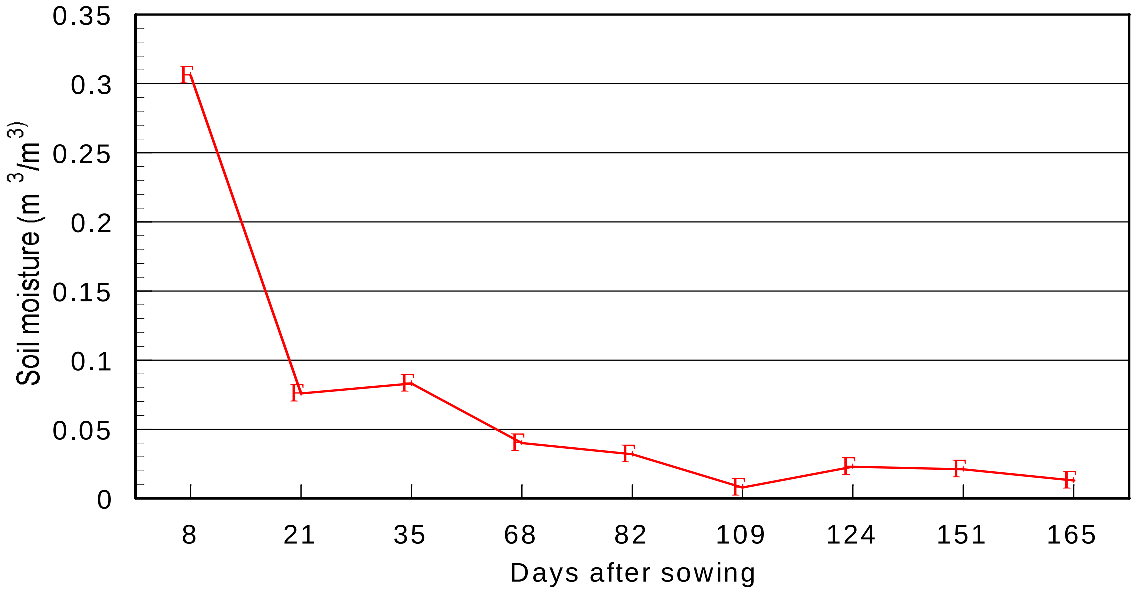


Table 3.8.1. The winter wheat harvest parameters in the 1999/2000 season

Previous season treatments	Total fresh plant (kg/ha)	Total fresh straw (kg/ha)	Yield (kg/ha)	W. 1000 grains (g)	Lengths of spike (cm)	Heights of spike (cm)
D	12638.1	9286.5	3019.8	49.2	6.3	69.7
C	11223.1	8182.1	2756.7	49.7	6.3	68.1
C+P	13063.6	9290.1	339.4	50.0	6.3	67.8
C+P+S	14080.7	10048.8	3544.2	51.0	6.2	72.6
C+P+IS	12250.6	8709.6	2909.3	50.0	5.9	67.9

Table 3.8.2. The winter wheat harvest parameters in the 2000/2001 season

Previous season treatments	Total fresh plant (kg/ha)	Total fresh straw (kg/ha)	Yield (kg/ha)	W. 1000 grains (g)	Lengths of spike (cm)	Heights of spike (cm)
D	5741.6	4121.9	1178.6	48.9	4.9	54.8
C	6603.7	4388.6	1533.4	52.2	5.2	56.0
C+P	6611.7	4714.9	1058.6	49.1	5.7	53.8
C+P+S	5414.9	3688.5	1251.1	50.0	5.5	55.8
C+P+IS	6115.0	4149.5	1384.5	50.4	5.4	56.0

Summary of Results

Three years of results can be summarized as follows:

1). Total rainfall in 1999, 2000 and 2001 years were 1028.7, 793.4 and 847.0 mm. Although the amount of rainfall in 1999 was greater than the other two years, it was very changeable and little rain fell 40 days after sowing. The amount of rainfall was least in 2000 among these three years, but the distribution was even and 82.2% of rain fell in the cropping season. In 2001, there was more rainfall at the crop early stage and the distribution was evenly spread. However, an unexpected heavy hail storm (9 August 2001) occurred during the silking stage. These patterns of rainfall during the growing seasons had a strong bearing on the effects of the polythene mulch.

2). Polythene mulch usually caused distinct and significant increases in temperature, especially during the crop early stage, particularly when measured in the early to late afternoon (in 1999). Straw mulch had the opposite effect and relatively low soil temperatures were found.

3). Soil moisture was high under polythene mulch during dry weather, but relatively low values were found during the periods of higher rainfall. Soil under straw mulch had high soil moisture during the whole cropping season in 2000 and 2001.

4). Changes in soil bulk density were mainly affected by amounts of disturbance rather than treatments. Usually, high soil bulk density was found under non-mulched treatments than mulched treatments before disturbance.

5). It is difficult to identify the effects of different treatments on soil chemical properties over three years. However, contour cultivation plus polythene and straw mulch appeared to be associated with increases in total K and intercropping with soybean contributed some additional soil N.

6). Intercropping with soybean facilitated early canopy growth and increased surface cover, possibly contributing to improved soil conservation.

7). Contour cultivation with polythene, contour cultivation with polythene and straw mulch and polythene with intercropping soybean all significantly increased maize growth, GLAI and yield compared to downslope cultivation. Based on sampled plants, C+P had the highest yield in 1999, C+P+S gave the highest yield in 2000 and C+P+IS gave the highest yield in 2001. There were no significant differences between these three treatments.

8). From cost-benefit analysis, contour cultivation with polythene mulch gave the highest net return in most years. Intercropping maize with soybean gave a high net return when both crops had a good yield. Contour cultivation with polythene and straw mulch gave an intermediate return, with the increased output not covering the cost of the straw mulch. Contour cultivation alone gave a higher net return than traditional downslope cultivation.

Chapter 4 Discussion and Conclusions

Introduction

In this chapter, the findings of three years of results are discussed. Firstly, the effects of five different cultivation techniques on soil physical properties and soil chemical properties; next the effects of these treatments on crop development and yield, together with the possible economic benefits. Finally, there is a discussion of the limitations of the study and future suggested work suggestion followed by general conclusions.

4.1 Soil temperature

Soil temperature is one of the important factors that control seed germination, crop growth and biological activities. It is widely understood that temperature has a major influence on crop development and yield (Shul'gin, 1965; Nielsen and Humphries, 1966; Cooper, 1973; Warrington and Kanemasu, 1983). It has been shown that soil temperature affects dates of emergence (Hayhoe and Dwyer, 1990; Hayhoe *et al.*, 1996) and silking and maturity (Cutforth and Shaykewich, 1989). Several studies have shown that in cool temperate regions increased soil temperature increases yields (Willis *et al.*, 1957; Allmaras *et al.*, 1964; Watts, 1973; Bollero *et al.*, 1996).

Different crops have different ranges of soil temperatures at which their growth and yield are maximized, such as 25-30°C for tomato and soybean and 15-20°C for potato (Launders, 1971). Maize can germinate at relatively low temperatures of 10-15°C (Blacklow, 1972), but growth is maximized at high temperature (Hall and Ziska, 2000). The optimal soil temperature was 27.4°C, based on studies in the northern USA (Allmaras *et al.*, 1964). Walker (1969) also reported that maximum dry matter and total leaf length of developing maize seedling was at soil temperatures of 26-27°C. Pursglove (1972) reported that maize grew best at an average day temperature of 24°C and night temperature of 14-16°C. The optimum root temperature range for maize seedling was reported to be 20-30°C (Grobbelaar, 1963). Willis *et al.* (1957) reported an optimum soil temperature for growth of 23°C at 10-cm depth in central Iowa; temperatures either lower or higher resulted in less grain yield.

Although maize is a warm season crop (Hall and Ziska, 2000), high soil temperature can reduce plant emergence and damage the components needed for leaf photosynthesis and reproductive development (Hall, 1992), especially if soil temperature is >40°C (Harrison and Lal, 1979; Shun, 1997). Lal (1974) reported that the constant root temperature of 35°C and fluctuating temperature between 30-40°C significantly decreased shoot and root growth and transpiration rate. On average, there was a 3 cm decrease in height per degree increase in root temperature from 30-38°C. Grobbelaar (1963) found that the transpiration rate of maize was decreased and N, P and K uptake retarded at a root temperature of 40°C. Walker (1969) related Ca and B deficiencies of maize seedlings to high root temperature. Walker (1969) found that even 1-deg C difference in soil temperature (ranging from 12-35°C) influenced the growth behaviour of maize seedlings. With each degree increase in soil temperature from 26-35°C, total dry weights averaged 12% less than weights at each previous soil temperature.

Generally, soil temperature and moisture are controlled by weather conditions. However, micro-climatic environments can be created in the seedling rows (row zone) and within-row (inter-row zone) by mulching either of the two zones (Nelson and Allmaras, 1969; Adams, 1970; Allmaras and Nelson, 1971; Lal, 1974). Beatley (1974) and Veenendaal *et al.* (1996) reported that the most important environmental factors controlling successful germination and subsequent establishment in dry climates are rainfall amount and distribution and heterogeneity of soil moisture. Relative humidity, evaporative demand and temperature act interactively and may also control germination (Tischler and Voigt, 1983; Frasier *et al.*, 1987), but the microclimatic factors, such as shade provided by the plant canopy and mulch, can also influence seedling emergence and growth (Veenendaal *et al.*, 1996). Stone *et al.* (1999) used polythene sheet (25.2°C) and straw mulch (18.3°C) to modify soil temperature to achieve high and low temperatures.

Considering the data of the Delta T-logger at the experimental site, the mean air temperature and soil temperature (15 cm depth) at the seed germinating stage were 17.7 and 18.8°C, respectively. In relation to the reported optimum temperature of 24°C (Purseglove, 1972) for maize seeds germination, the local temperature was 5-

6°C lower than the optimum, but 5-7°C higher than the 12°C threshold needed for seed germination (Shun, 1997). During the vegetative growth stage, the mean values of both air and soil temperature were ≤21°C and 21.5°C, which was still 5-6°C lower the optimum temperature of 26-27°C (Allmaras *et al.*, 1964). These data suggest that an increase in average soil temperature would increase maize growth. This provides one of the possible explanations for the effects of polythene mulch.

4.1.1 Treatment effects: polythene mulch (C+P)

The clear polythene allows solar radiation through to the soil and the heat trapped beneath the polythene then increases substantially soil temperature. Considering three years of results, polythene mulch significantly increased soil temperature early in the season. In 1999, the one occasion when a significant result was not found at all soil depths at 20 DAS, was at 0700-0800. Mean seasonal soil temperatures were 24.8, 23.2, 22.3 and 21.6°C at the soil surface, 5, 10 and 15 cm depths, respectively. They were means of 1.2, 0.2, 0.1 and 0.2°C greater than non-mulched treatments. Considering optimum temperature of 26-27°C, these were still at least 1-2°C below optimum, but it has been shown that, a rise of 1°C can increase maize seedling growth by 20% (Walker, 1969). Stone *et al.* (1999) found that biomes and yield increased by 21% between the 18.3°C and 25.2°C soil temperatures. This occurred because increased soil temperature accelerated the rates of leaf tip appearance and full leaf expansion, enabling the crop to more rapidly attain maximum Green Leaf Area Index. This enabled better synchrony between time of peak radiation interception and peak radiation incidence. They found grain yield increased by ~0.3 t/ha per 1°C increase in average soil temperature across the range 18-25°C. Bollero *et al.* (1996) also reported that 0.14 t/ha per 1°C increase in average soil temperature.

In 2000, soil temperature under polythene mulch over the crop season was usually 1°C higher at both 1 and 5 cm soil depths than the non-mulched treatments, such as D and C. The difference between them in this year was not greater than the other two experimental seasons. The reasons were probably that the low air temperature and more cloudy days decreased radiation input to the polythene.

In 2001 the temperature under polythene at 5 cm-soil depth was usually 2.2-4.3°C higher than non-mulched treatments during the seed germinating stage (before making a hole from polythene). The temperature at this stage may have been crucial for seed germination and seedlings development. Within the first week most seedlings were observed at the surface under the polythene treatments, while there was no seedling on the non-mulched treatments, emergence was delayed at least 2-3 days compared with polythene mulch. After breaking the polythene to provide for seeding growth, the effect of polythene on soil temperature diminished slowly, until 43 DAS. The temperature differential decreased under polythene much at these later stages probably for two reasons. One is that the broken polythene changed the microclimate, which allowed more air exchange between the polythene and outside, and thus evaporation started to return to normal. Another reason is that the developing crop shaded solar radiation from falling on the polythene. Prihar *et al*. (1979) reported that under irrigated conditions the maximum temperature was 41.7°C and 37.8°C at 5 and 10 cm depths, respectively, under sparse maize cover (LAI = 0.52). However, it decreased to 32 and 31.5°C, respectively when the canopy was fully developed (LAI = 5.88). Ghuman and Lal (1983) found when the crop was not under moisture stress, an increase of maize canopy from 0-59.7% decreased the soil temperature range from 10.6 to 4.3°C at 1 cm and from 3.2 to 1.6°C at 20 cm depth.

During later crop stages, the seedlings have been established and the air temperature was sufficiently warm to allow healthy crop growth. The polythene mulch seemed unimportant from then on to the end of the growing season. From the opposite view, the excessively high temperature would adversely affect the crop (Harrison and Lal, 1979). Gernmàn *et al.* (1996) reported previous leaves are more affected by soil temperatures up to leaf 6, while for later leaves air temperature plays a major role (Thiagarajah and Hunt, 1982). Gernmàn *et al.* (1996) reported that the effect of early season soil temperatures can be extended up to at least leaf 13.

In 2001 one extreme soil surface temperature was observed under polythene mulch (41.1°C) at 1400-500 at 27 DAS (see Table 3.2.2). At this temperature crop growth would be adversely affected (Harrison and Lal, 1979). However, soil temperature at 5 cm-soil depth was just 27.8°C. The crop growth was normal, which suggested this extreme soil temperature did not occur often and did not have any lasting detrimental effect on root growth. The effect of polythene mulch increasing soil temperature is widely reported. Gupta and Gupta (1980) found mean maximum soil temperature was higher under polyethylene and at 5-cm depth was higher by 1-3°C.

4.1.2 Treatment effects: Polythene plus Straw mulch (C+P+S)

In 1999, measurements were taken only under the polythene mulch and mean seasonal soil temperatures were 24.14, 22.98, 22.14 and 21.49°C at the soil surface, 5, 10 and 15 cm depths, respectively. The values were lower then the single polythene mulch C+P treatment (means 24.77, 23.18, 22.27 and 21.64°C) and the difference was not greater between non-mulched treatments, except the soil surface temperature (0.56°C difference between them). In 2000 and 2001 for C+P+S soil temperature under both polythene and straw mulch was measured. Polythene mulch increased soil temperature by 1°C at the soil surface and 0.7°C at 5-cm depth in 2000 and 2.1°C at the soil surface and 0.5°C at 5-cm depth in 2001, respectively. The opposite results were obtained under straw mulch between the rows, straw mulch reduced soil temperature 1°C at the soil surface and 0.5°C at 5-cm depth in 2000 and 1.1°C at the soil surface and 0.4°C at 5 cm depth in 2001, respectively. For this treatment, the polythene mulch tended to increase soil temperature, while straw mulch decreased soil temperature, especially at mid to late crop stages.

Barton (2000) found in the local climate of Yunnan, polythene mulch produced higher temperature early in the season, with little change under straw. On the same experimental site, Milne (2001) did not include polythene treatments but observed that soil temperature was significantly lower under straw mulch. Adeoye (1984) found maximum temperature at a soil depth of 5 cm in non-mulched plots were consistently in the range 38-43°C. Application of grass mulch at 5 t/ha reduced maximum temperature at 5 cm by ~7°C and at 10 cm by 4°C. Gupta (1980) also found mean maximum soil temperature was lower under millet husk mulch compared to the control (without mulch). Soil temperature at 5 cm depth was lower by 2-4°C under millet husk. Lal (1974) reported that mulching significantly decreased the maximum soil temperature at 5, 10 and 20-cm depths. Initially during growth, temperature differences ≤8°C were observed between mulched and non-mulched plots at 5-cm depth. Asghar *et al*. (1987) found that coconut frond mulch application decreased soil temperature by an average of 1.8°C.

4.1.3 Treatment effects: Polythene mulch plus intercropping (C+P+IS)

Measurements of soil temperature of this treatment was under the polythene rather than soybean row, so the actual value was the effect of polythene mulch. The mean 1999 season soil temperature under intercropping polythene mulch were 24.6, 23.5, 22.6 and 21.93°C at the soil surface, 5, 10 and 15 cm, respectively, while under D values were 23.6, 22.9, 22.2 and 21.5°C, respectively. Under C values were 23.7, 22.8, 21.9 and 21.3°C, respectively. The difference between intercropping polythene and D were 1.0, 0.6, 0.4 and 0.44°C at the respective soil depths. The difference between intercropping polythene and C were 0.9, 0.8, 0.7 and 0.7°C, respectively. Although the difference over the season was not great, the larger difference occurred at the crop early stage, such as at 1400-1500 on 20 DAS, the difference between intercropping polythene mulch and D, C were 7.7 and 7.8°C, respectively.

In 2000 the mean seasonal soil temperature of intercropping polythene mulch, D and C at 1 cm soil depth were 22.9, 20.8 and 20.7°C, respectively. The difference between them were 2.1 and 2.2°C, respectively. The difference between them at 5 cm was also ~2°C.

The polythene mulch had a greater effect on soil surface temperature in 2001 than 2000, possibly associated with the average higher air temperature. Mean soil surface temperature were 25.0, 22.0 and 22.3°C for C+P+IS, D and C, respectively. The differences between the treatments were 3.0 and 2.7°C, which was greater than in 2000. However, soil temperature at 5-cm depth between the treatments was not higher as in 2000, the difference was just 1.8 and 1.6°C, respectively.

The soil temperature between the soybean rows was not taken in this study, the soybean canopy was very bulky and extensive sampling would have been necessary to produce representative data. But Olasantan (1988) found maize intercropping with melons can raise soil temperature in the upper 10 cm at 0600, but decreased temperature at 1000, 1400 and 1800. However, Barton (2000) found no clear soil temperature effect of maize intercropping with soybean.

4.1.4 Treatment effects: Downslope (D) and Contour cultivation (C)

The experiment also included contour cultivation which was selected primarily to improve soil conservation compared to the traditional method of downslope cultivation. Therefore, marked effects on soil temperature were not expected and the results from these two treatments were quite similar over the three years. There were no significant differences between the two treatments, although there was a trend for C to give slightly high soil temperatures. It is probable the cultivation direction of contour cultivation intercepts more solar radiation than downslope, depending on aspect. However, this assertion requires further research.

4.2 Soil moisture

In addition to soil temperature, soil moisture is also one of the important factors affecting crop growth. It has been suggested that, in dry environments, soil water and temperature are the key factors affecting seed germination (Potter *et al.*, 1986; El-Sharkawi and Farghali, 1988). Seed germination and seedling establishment are the two critical steps in the life cycle of most plants (Esler and Phillips, 1994; Gutterman, 1994). Parmar and Moore (1966) recorded quite marked reductions in maximum germination of maize at osmotic potentials of –0.8 and –1.0 Mpa. However, Doneen and MacGillivray (1943) and Hunter and Erickson (1952) reported that maximum germination of maize did not decline until soil moisture potentials fell <–1.5 and –1.27 Mpa.

The moisture regime during the pre-silking period has been shown to be important for both the development of vegetative structures, which later determine the dry matter producing capacity of the plant and the development of reproductive structures. Significant reductions in plant height have been commonly reported from stress periods ranging upwards from 8 days of wilt (Robins and Domingo, 1953; Denmead and Shaw, 1960). Observations indicated that short stress periods had their greatest effect late in the vegetative period, this was demonstrated by maximum height reductions of 6.4-15.2 cm. Early stress periods occurring during rapid elongation of the lower and middle internodes reduced final dry weights. The effects of moisture stress on final dry matter yield of each vegetative component was closely related to the coincidence of the water deficit with the initial (or) rapid growth phase of the respective period (Classen and Shaw, 1970). Several authors observed a reduction in grain yield from water deficits during the early stage, ranging from 21% (Denmead and Shaw, 1960) to 48% (Barnes and Woolley, 1969). Denmead and Shaw (1960) observed a 25% yield reduction from two stress cycles totalling 8 days of wilt during the vegetative stage. The yield reduction was >40% as a result of 4-8 days of wilt at silking (Robins and Domingo, 1953; Denmead and Shaw, 1960; Barnes and Woolley, 1969).

In real situations, there are few or no irrigation systems on Yunnan sloping land, most crops being rain-fed. The precipitation pattern of Yunnan is that 85% of rainfall is concentrated in the summer season and the spring season is usually dry. Although the amount of water required for maize growth is enough from rainfall, the rainfall distribution is sporadic and unevenly spread over the cropping season. The rainfall usually starts in May, but in abnormal years, the rainfall comes late and can be delayed to June, periods crucial for seed germination and establishment. So in this area, soil moisture can be a serious factor for crop growth, particularly for the early crop stage.

4.2.1 Treatment effects: polythene mulch (C+P)

The effect of polythene for soil moisture depends on rainfall and the timing of polythene application. The impermeability of the polythene can prevent rainfall penetrating into the soil, so causing low soil moisture. On the other hand, if the soil is irrigated prior to application, or early rainfall is high, high moisture in the soil can be retained below the polythene because of decreased evaporation. The opposite trends were observed in 1999, 2000 and 2001. During 1999, soil moisture did appear to be limited at the seedling development stage, when from 22-45 DAS rainfall was just 24.3 mm. Signs of wilting plants in non-mulched plots were observed, especially during daytime. During this drought period, polythene mulch markedly retained soil moisture loss. The 5 cm soil moisture was 15, 11.2 and 10.5% for C+P, D and C, respectively. These substantial differences may have been responsible for the marked effect of C+P treatment on crop yield in this season, compared to 2000 and 2001. This will be discussed in Section 4.5. Unfortunately, an equitensiometer probe was not available in 1999 to measure soil matrix potential.

The greater retained soil moisture under polythene mulch at this crucial stage delayed wilting time compared with non-mulched treatments. Harrison-Murray and Lal (1979) also found that polythene mulch delayed the onset of wilting by about five days during a period of water stress, which highlighted the effectiveness of polythene for water retention during dry weather. As mentioned above, polythene mulch has two functions for soil moisture. One is to retain soil moisture during dry weather. Another is preventing more rainfall directly falling to the soil, which leads to lower soil moisture in wet weather. It was for this reason that a double ridge system was developed, to increase water infiltration below the polythene. Soil moisture did not appear to be limiting during both the 2000 and 2001 seasons. This was confirmed by measurements of soil potential. The data showed there was no water stress during either entire season. It seemed that the soil was always sufficiently moist during these two seasons, consequently the effects of polythene on yield were less marked.

Soil moisture under polythene mulch was lower than under non-mulched treatments. In the 2000 season, soil moisture at 6 cm soil depth was 0.27, 0.25 and 0.17 m^3/m^3 for D, C and polythene mulch C+P, respectively. Thus, the difference between the treatments was -0.1 and -0.08 m^3/m^3. Even soil moisture was higher in 2001, the difference between D, C and polythene mulch was still -0.04 m^3/m^3, although it was less than in 2000. The low moisture under polythene mulch did not mean plants had insufficient water. On the contrary, soil moisture at the plant base was high and the same as the non-mulched treatments. This suggests that the double ridge may have had some effects in improving water penetration past the polythene cover.

4.2.2 Treatment effects: polythene plus straw mulch (C+P+S)

Polythene mulch on this treatment performed similarly to C+P, but in addition to the effect of polythene mulch, straw mulch had its own affects on soil moisture. Although soil moisture measurements were not taken under straw mulch during the 1999 cropping season, the results from 2000 and 2001 confirmed that straw mulch retained significantly higher soil moisture during these two wet seasons. The mean soil moisture was 0.34 m^3/m^3 under straw mulch in both seasons, which was 0.07 and 0.03

m^3/m^3 higher than the non-mulched treatments. Similar results were found by other researchers in Yunnan (Barton, 2000; Huang, 2001; Milne, 2001; An, 2002). Simpson and Gumbs (1986) found beneficial effects of applying straw mulch over conventional tillage without mulch in their study in a heavy clay soil in Guyana. Mulched plots had higher soil moisture at both 0-15 and 15-30 cm depths compared with non-mulched plots, which was particularly beneficial during drought stress periods. Adeoye (1984) found application of grass mulch at 5 t/ha soil retained higher moisture to ≤60-cm depth. Conservation of moisture under the grass mulch was associated with surface conditions that maintained good infiltration and reduced evaporation.

Considering the benefits of polythene and straw mulch, polythene mulch has a main function of increasing soil temperature, while straw mulch decreases soil temperature. Polythene mulch impedes rainfall directly infiltrating the soil, but straw can retain more soil moisture. Both mulches can reduce evaporative losses, maintain topsoil structure and prevent soil surface crusting from raindrop impact. No water stress was observed in C+P and C+P+S treatments.

4.2.3 Treatment effects: Polythene mulch plus intercropping (C+P+IS)

On this treatment, measurements were taken under the polythene rather the soybean rows. Considering the data of three years results, the soybean may have acted similarly to straw mulch, in providing additional ground protection from raindrops, thus increasing infiltration and topsoil moisture. Olasantan (1988) found intercropping maize with melons increased soil moisture by ~30% at 10 cm depth. This may be because melons protected the soil against insulation, helping water to infiltrate into the soil and minimizing heat and water loss by evaporation during the day and inversion of the temperature gradient at night. Melons can be used as a living mulch.

4.2.4 Treatment effects: Downslope (D) and contour cultivation (C)

For cultivation direction, there was no distinct differences between downslope and contour cultivation in terms of soil moisture. It is difficult to ascertain whether soil temperature and moisture is more important in the field. Soil temperature regime is strongly influenced by the interaction between canopy cover and soil moisture regime. When soil moisture was >0.08 cm^3/cm^3, plants were protected against temporary wilting in the second half of the day and the 5-cm soil temperature decreased with an increase of maize canopy. However, when the soil moisture was <0.08 cm^3/cm^3, the 5-cm maximum soil temperature under maize was higher by 3°C than in an uncropped flat seedbed (Ghuman and Lal, 1983). Allmaras and Nelson (1973) reported that temperature had a greater effect than moisture stress on seeding growth, over a mean soil temperature range of 10-19°C. A difference of 1°C resulted in large changes in maize root dry weight and lateral spread, while small differences in soil moisture tension had little effect. In the temperature range 19-21°C, there was little response to temperature differences of 1°C, but there was a response to differences in soil moisture tension as small as –0.0002 Mpa. However, Pesant and Cheng (1984) found increasing temperature from 15-26°C increased maize DM yield by 26%. When the moisture content of the pure quartz sand pots was increased from 30 to 90% of field capacity, DM yield increased by almost 30%. There was a significant interaction between temperature and moisture regimes on yield and levels of B, Mn and P in the aerial parts of the plants.

4.3 Soil bulk density

Soil with higher bulk density usually has less pore space and this may restrict root penetration and spread. Soil bulk density is affected by the different soil types, it is easily disturbed by plant cultivation, machine compaction and material additions, such as soil amendments and manure. Therefore, reliable and reproducible values for soil bulk density can be difficult to obtain and evaluate.

It is not clear what the level of soil bulk density is ideal for crop growth on all types of soil. However, some studies have been conducted in predicting detrimental effects to plant growth. Bulk density >1.2 $Mg.m^{-3}$ for clay, 1.6 $Mg.m^{-3}$ for loam soil, and 1.8 $Mg.m^{-3}$ for sandy loam adversely affected the root growth of rice (Ksrm *et al.*, 1976). Singh *et al*. (1992) stated that the maximum value of bulk density that may be tolerantly by plants is 2.1 $Mg.m^{-3}$ in any type of soil.

A bulk density of 1.60 $Mg.m^{-3}$ is presumed to limit root growth on many soil types. Soil bulk density is one of the indices of soil compaction. Veihmeyer and Hendrickson (1948) reported that soil compaction reduces root growth and can decrease crop yields. For each 1 $kg.m^{-3}$ increase in bulk density, there was a decrease in maize grain yields of 18% relative to the yield on a non-compacted plot (Canarache *et al.*, 1984). Pot measurements in a sandy loam soil found with increasing bulk density from 1.00-1.60 $Mg.m^{-3}$, total numbers of bacteria, fungi and actinomycetes declined by 26-39%. The greatest activities of most soil enzymes occurred at a bulk density of 1.0-1.3 $Mg.m^{-3}$, which are optimum for most field crops (Li *et al.*, 2002).

Under no-tillage, straw mulch reduced soil bulk density after two years (Frainzen *et al.*, 1986). Some studies have shown mulching to lead to decreases in soil bulk density and increases in porosity, even under the normal tillage operations (Gupta and Gupta, 1986; Fan *et al.*, 1993). However, others found mulching to have no significant effect on bulk density (Mannering and Veyer, 1963; Mbagwu, 1984). Simpson and Gumbs (1986) found that mulching had no significant effect on soil bulk density at 0-5 cm depth on heavy clay in Guyana.

Considering the results of three years, the data were very variable among the treatments, but few measurements were >1.40 $g.cm^{-3}$, which indicated the bulk density did not greatly limit root growth, with the optimum being ~1.30 $g.cm^{-3}$ (Li *et al.*, 2002). Although in this study measurements were just in the 0-20 cm tillage layers.

It is difficult to compare the data between different years among the treatments, due to amounts of disturbance, such as tillage, weeding, fertilizer application and winter wheat planting. Within the years, C+P, C+P+S and C+P+IS had few disturbances from weeding, which loosens the soil. It was expected that mulch could prevent raindrop impact and maintain lower soil bulk density, as observed by Gupta and Gupta (Gupta and Gupta, 1986; Fan *et al.*, 1993). Soil bulk density at 0-10 cm depth was more variable than at 10-20 cm depth. Considering the data, generally, at the beginning of the season, the lower bulk density was at 0-10 cm, while the highest values were at 10-20 cm depth. This would have been the result of recent tillage operations, loosening the soil. However, at the end of the season, the reverse effect occurred, with a higher bulk density in the 0-10 cm depth than in 10-20 cm depth. This suggested that agricultural practise disturbed soils below this depth.

Generally, under these typical agricultural practises, it was very interesting that before weeding disturbance, mulch treatments seemed beneficial for soil bulk density. The significant treatment effects were observed in both 2000 and 2001 at the early crop stage, the difference between mulch treatments and D was –(0.05-0.12) g cm^{-3} and –(0.03-0.07) g.cm^{-3} in 2000 and 2001, respectively. However, after disturbance, the reverse result was obtained that lower soil bulk densities were observed on non-mulched treatments rather than on mulched treatments, due to soil loosening by weeding.

In 1999, soil bulk density under all the treatments increased at the end of the season, the reason probably is that intense rainfall in this year compacted the soil again on the non-mulched treatments, as they experienced soil loosening after weeding. The lower bulk density increase of mulch treatments suggested that the mulch might protect the soil from direct rainfall compaction, so that soil structure remained relatively intact throughout the season.

4.4 Soil nutrients

A three year field research programme is a relatively short period over which to monitor changes in soil nutrients due to cultivation practises, especially when the experimental plots received applied fertilizer at the beginning of each cropping season. Consequently, it was not surprising that there were relatively few treatment effects. However, soil fertility is an important aspect of sustainability, so it was important to monitor any possible changes.

4.4.1 Total nitrogen, phosphorus and potassium

Generally, total N and P were relatively stable, especially P. Variable results were obtained for total K. Moody *et al*. (1952) found total N in soil increased under mulch tillage in Virginia, USA. In this study, the only detectable treatment effect over three seasons was C+P+IS, which could be due to the soybean fixing nitrogen. However, intercropping soybean did not show significant N increase, the reason may be that soybean plants were removed after the harvest. It was difficult to establish the effect of straw mulch on total N. In 1999, it did not show any contribution for total N, while the reverse result was obtained in 2000. There were similar patterns for total K, it showed an increase in 1999 and a decrease in 2000. But after three seasons' experiments, both C+P+S and C+P+IS gave apparent increases in total K. These increases were probably contributed from the decayed straw and decomposed soybean leaves, respectively. There was no clear difference between contour and downslope cultivation in this study. However, Bhatia and Choudhary (1977) found contour cultivation significantly reduced the depletion of total N compared with downslope cultivation on a 2.2% slope. For P, small changes were found among treatments. Jiang *et al*. (1986) reported that it is possible that P is mainly attached to sediments in red soils in southern China.

4.4.2 Available nitrogen, phosphorus and potassium

In comparison to the total forms, there were more trends apparent between treatments. The effects of straw mulch on soil nutrients are complicated. A hypothesis was that straw is a potential source of additional N. However, it will take a long time to decompose. In the initial stage of decomposition, straw can compete with the crop for soil available N. Kitou and Yoshida (1994) showed soil available N to be lower under mulched compared with non-mulched soil two weeks after application, but to be higher 10 weeks after application.

Effects of C+P+S on soil available N and P over three years were indistinct. However, an increase in available K was observed, which suggests that decomposing straw was acting as a source of additional K. This was agreed by many researchers (Hagger *et al.*, 1991; Patil *et al.*, 1993; Kitou and Yoshida, 1994) that soil K levels increased under decomposing wheat straw. The available N on C+P+IS was consistent with the total form, with the highest treatment value after the experiments. However, available K did not seem to accord with total forms, with no distinct change found.

As with total forms, there were no clear differences in available N, P and K between contour and downslope cultivation. However, Bhatia and Choudhary (1977) found contour cultivation significantly increased with soil available N and total N.

4.4.3 Soil organic matter and pH

Soil organic matter (SOM) is one of the important indexes of soil fertility. SOM increases soil water holding capability, supplies nutrients, improves soil structure, and minimizes soil erosion (Fitzpatrick, 1986). During the experiment duration, there were no significant effects among treatments. The values of different treatments range from 1.11-1.26% at the beginning of the field experiments, while the values range from 1.24-1.33% at the end of the three years of field experiments. The increasing organic matter for treatments was probably contributed by the addition of manure each year. SOM in this area is generally low (Tang, 1993). On red soil, SOM is low when the value is <1.0%, medium at 2-3% and high at >3%. Generally, sub-tropical soils have lower levels of SOM than temperate soils, as decomposition rates are higher (Landon, 1991). Barton (2000) found that adding soybean biomes or straw residue increased SOM. However, in this research, intercropping soybean did not show significant increases in SOM. The reason may be that soybean plants were taken out after the harvest rather than left in the soil. But surprisingly, straw mulch also did not increase SOM, even when left in the soil during the whole experimental programme. This can be explained two reasons. One, probably due to the short duration of the experiment, this can not dramatically change soil properties. Secondly, manure inputs each year may have masked the effects of straw and/or soybean.

Soil pH is an indicator of soil acidification and often affects the availability of many other elements in the soil (Cliff, 1985). In Yunnan Province, 65% of soil is classified as red soil and pH is in the range of 5.0-6.5 (Chen and Hao, 1990). Generally, the optimum pH for most plant growth is from 5.0-7.5 (Fitzpatrick, 1986). In this research, soil pH was under this range among the treatments. The interesting finding was that soil pH under downslope cultivation always had the lowest value, probably due to high soil erosion rates.

4.5 Crop development and yield

Crop yield is the result of an integration of different factors, such as climate, soil, cultivar and agricultural management. Reviewing the weather over three years, 1999 was a period of early season drought. Although rainfall amount was highest in 1999, the distribution was variable, with lower than average rainfall in late May/June, leading to symptoms of water stress in the non-mulched maize crops. Between 22-45

DAS (which is a crucial stage in maize growth) there was only 24.3 mm of rainfall. The amounts of rainfall of 2000 were less, but distribution more evenly and regularly spread over the seasons. The weather of 2001 was favourable, but experienced a heavy hail storm after the maize silk had just established. So the research finding is very valuable for the field situation under different weather conditions.

The data of three years showed significant treatments effects, confirmed by crop growth, maize yield and other harvest parameters. Yield differences between treatments were more pronounced in 1999 than in 2000. This probably resulted from the fact that 2000 was a favourable season in terms of moisture availability and rainfall distribution through the season. Therefore the maize was less likely to undergo periods of stress compared to the 1999 season. Significant treatment effects were still observed in 2001 even after the hail storm, but the absolute values cannot be compared with the other two seasons, because of the hail damage.

4.5.1 Treatment effects: Polythene mulch (C+P)

High soil temperatures under polythene mulch (as discussed in Section 4.1.1) allowed seeds to germinate and seedlings to become well established. This then led to rapid crop development to maximum plant height and extends of the largest leaf area. This advantage allowed the canopy to intercept more solar radiation for photosynthesis.

The pronounced significant effect of contour cultivation with polythene mulch on crop growth was observed in all three experimental years. This was interpreted by plant height and GLAI. Plant height indicated the rate of plant growth and GLAI showed how plant canopy developed.

Polythene mulch produced taller plants compared to contour cultivation alone just 20 days after sowing and this advantage continued throughout the growing season. This more rapid growth also produced greater GLAI values. The difference decreased towards maturity, as the more rapid development led to slightly earlier senescence of the basal leaves.

Despite the difference in the season, flowering date were similar. For polythene mulch the date of threshold of silk and onset of cob development were observed on 21, 24 and 24 July in 1999, 2000 and 2001, respectively. This suggested that from this point, vegetative growth transferred to reproduction stage. The polythene mulch treatments were 3-7 days more advanced compared with no mulch treatments.

Considering the results of three seasons, in terms of crop growth and canopy development, the effect of polythene mulch slowly diminished, but benefit effects were maintained until harvest. This result is similar to both Barton (2000) and Huang (2001), which they found the most influence for polythene mulch was at the start of the season. However, as the crop developed and the surface became increasingly shaded, the effectiveness of polythene mulch diminished and the difference between treatments decreased.

Good seedling establishment and crop development contributed to high crop yields. Maize yields were higher in 1999 than in the two later seasons. The highest yields on the experimental plots were from the contour cultivation with polythene mulch treatment. The yield was 1.54 times more than downslope cultivation without mulch treatment and 1.38 times with contour cultivation without mulch treatment. The benefit of polythene was 38.5% more yield than on the contour cultivation.

The yield under polythene mulch in 2000 was not as marked, with no significant treatments effects based on plot determination. However, it was still 1.21 times compared with downslope cultivation without mulch and 1.08 times with contour cultivation. The decreased benefit of polythene mulch in this season may be due to the favourable weather with evidence of early season water stress. Probably the benefit of polythene mulch on this season was on soil temperature alone, rather than in combination with soil moisture. It was difficult to compare the yields in 2001 with other two seasons due to the hailstorm. However, within the year; treatment effects were still observed. The yield under the polythene mulch treatment was 1.33 times compared with downslope cultivation without mulch and 1.24 times with contour cultivation without mulch. Maize cob development was well established before the hailstorm, which prevented complete crop failure. However, the yield reduction was 2152.7 kg/ha for contour cultivation without mulch compared with the 2000 yield and 1218.1 kg/ha reduction for polythene mulch. This confirmed that polythene mulch reduced the risk of yield loss following this typical and frequent storm-phenomenon and showed the importance of good seedling establishment for final yield.

Barton (2000) and An (2002) observed that the highest yield was under polythene mulch in small erosion plots at YAU. Huang (2001), working in the same catchment, found that the yield under polythene mulch increased 50.0 and 61.1% compared with single contour in 1998 and 1999, respectively, and these yields were 1.5 and 2.8 times increases the mean Yunnan maize yield of 3.85 $t.ha^{-1}$ (Yunnan Provincial Yearbook, 1999). Similar findings were reported by Chen (1996) that polythene mulch increased soil temperature and soil moisture retention and maize yields in polythene mulch treatments were 127.5% of those of direct-sown maize. Radha *et al*. (1995) reported that polythene (PE) mulched plots recorded 15.5-28.9% greater plant diameter than non-mulched plots and gave similar results to leaf mulch. Soil moisture content in the topsoil layer (0-15 cm) was 87-113% higher with PE mulching than in non-mulched plots during extremely dry weather conditions, while with leaf mulch it was only 50% higher. Weed coverage was reduced by 84-90% with PE mulch and by 57% with leaf mulch. Furthermore, soil temperature fluctuations were reduced by mulching.

Considering the importance of temperature on crop growth, Fortin and Pierce (1990) concluded that a maize apical meristem exposed to 21.3 °C had a developmental delay of 7.7 calendar days at tasseling, relative to maize exposed to 24.8°C. In addition, they suggested that developmental delay was fully manifested at V4, and plants under cooler conditions never catch up with plants under warmer temperatures. The cooler treatment (15.3°C) had a developmental delay of –10 d at V5 compared with the warm (25.0°C) and seven calendar days delay at tasseling (Gernmàn *et al.*, 1996). Thiagarajah and Hunt (1982) found that previous leaves were more affected by soil temperatures up to leaf 6, while for later leaves air temperature plays a major role. Gernmàn *et al*. (1996) showed that the effect of early season soil temperatures can be extended up to at least leaf 13.

4.5.2 Treatment effects: Polythene plus straw mulch (C+P+S)

This treatment combines both the benefits of polythene and straw. As in the previous discussion, the polythene mulch tended to have higher soil temperatures, which can promote crop growth, while straw mulch between the rows led to higher soil moisture contents that can also aid crop growth while the water availability is limiting.

Few reports have combined both polythene and straw treatments, but several studies have focused on these treatments applied separately. Effects of polythene on crop development and yield have been discussed in Section 4.5.1. There have been many studies on the effects of straw mulch on crop growth and yield. Maurya and Lal (1981) found the maximum maize shoot elongation rate was 5.5 cm/day with straw mulch, while just 3.0 cm/day with a non-mulched ridged treatment. Furthermore, straw mulch had significant effects on root growth, plant vigour and grain yield. On a silt loam Alfisol in Columbus, Ohio (USA), there was 32.5% more grain on wheat straw mulch than non-mulched plots (Yildiz and Lal, 1996). Similar results were obtained by Adeoye (1984) where grass mulch increased maize grain yield by 15-22% and by ~10% in millet. Lal (1974) reported that under a tropical climate, the increase in maize grain yield due to mulching with rice straw mulch and forest litter mulch at 2 t/ha over a three-year period was 46, 52 and 22%, respectively. Mulched plants had a higher growth rate and increased vigour and chlorotic symptoms occurred on non-mulched plants. Increases in grain yield due to mulching were attributable mainly to decreased soil temperature, but partly to improved soil moisture regime. Similar results were observed by Tang and Zhang (1996); Huang (2001); Simpson and Gumbs (1986) and Asghar *et al.* (1987). However, Al-Darby and Lowery (1987) reported that lower soil temperatures associated with conservation tillage delayed maize growth and development, resulting in decreased plant height and total leaf area. Fortin and Pierce (1990) and Fortin *et al.* (1994) reported that mulch induced decreases in soil temperature and significantly delayed crop development compared with bare soils. Clearly responses to straw mulch depend on weather conditions during the growing season.

In soil erosion plots at YAU, Milne (2001) found there were no significant effects of straw mulch on plant growth parameters or grain yield in a wet season, but significant plant growth and yield increase under straw mulch was observed in a dry season.

Barton (2000) pointed out the potential yield increases under straw mulch was lower than under polythene mulch.

In this study, the polythene and straw mulch were not evaluated separately. The combination of polythene and straw mulch did not show any detrimental effects on crop growth and final yield over three seasons. The 1999 data showed that plant height under C+P+S had similar values to the C+P treatment. While the value of LAI did not follow this trend, the values were always lower than C+P except one occasion (115 DAS), but it ranked the second among the five treatments. Over three years there were generally no significant difference between C+P and C+P+S in relation to crop growth, confirming the lack of any detrimental effects. The yields over three years on this treatment followed the crop development trends.

In 1999, the yield of C+P+S was ranked second and followed C+P. In 2000, it had the highest yield and in 2001 it followed C+P+IS, but was still greater than C+P treatment. The difference between C+P and C+P+S was –385 kg, +207.2 kg and +148.1 kg per hectare in 1999, 2000 and 2001, respectively. The results suggest that the single polythene mulch could not always maintain the highest yield in the long term. However, polythene combined with straw can increase crop sustainability. This was confirmed by Barton (2000) and An (2002). Barton (2000) found that polythene mulch only produced highest runoff and soil loss compared with other treatments (Table 4.1). However, polythene incorporated with straw had the lowest runoff and soil loss (An, 2002) (Table 4.2).

Table 4.1. Mean runoff (m^3 ha^{-1}) and soil loss (t ha^{-1}) from the maize plots (Source: Barton, 2000)

Year	Conventional tillage	No tillage	Straw mulch	Polythene mulch	Intercropping
1995 Runoff	524.7	465.0	302.8	540.3	433.1
1996 Runoff	20.0	8.7	13.9	19.1	22.2
1995 Soil loss	8.7	7.9	2.0	7.6	5.6
1996 Soil loss	0.034	0.016	0.014	0.034	0.037

Table 4.2. Mean runoff (m^3 ha^{-1}) and soil loss (m^3 ha^{-1}) from the maize plots (Source: An (2002))

Year	Polythene mulch	Polythene with Straw mulch	Downslope cultivation
2000 Runoff	101.53	100.76	253.17
2001 Runoff	69.9	35.53	340.63
2000 Soil loss	0.44	0.23	1.92
2001 Soil loss	0.1	0.008	3.11

4.5.3 Treatment effects: Polythene mulch plus intercropping (C+P+IS)

Plate 4.1 shows crop growth under intercropping with polythene mulch compared to contour cultivation with no mulch in 1999. In dry weather, the intercropped plants under polythene were still vigorous and strong (top), while the plant under no mulch was withered and short (bottom). A combination of the moisture retention afforded by polythene and the ground cover of the soybean, protected the intercropping system from water stress.

Plate 4.1. Plant growth under polythene mulch plus intercropping (top) and contour cultivation with no mulch (bottom) during the 1999 early cropping season, when there was a prolonged drought, showing the stress effects in the non-mulched plot

However, in 2001, the yield of the intercropped maize was highest (but not significantly different from the other polythene treatments) when soybean yield was also higher than in 1999.

Barton (2000) found variable results with the intercropping treatment, although it generally produced higher yields than conventional tillage. In this study, intercropping with polythene mulch over three years was evaluated. In 1999, the yield under C+P+IS took third place, followed by C+P and C+P+S. The difference between C+P+IS and C+P was –994.3 kg/ha. In 2000, the yield still ranked third, but the difference was less than in 1999, the difference with C+P was –221 kg/ha. The greater change occurred in 2001, the yield under C+P+IS was the highest one among the five treatments, the difference between it and C+P was +410.8 kg/ha. Unfortunately, soybean was not grown on its own, so the effects of the intercropping could not be fully evaluated.

4.5.4 Treatment effects: Downslope (D) and contour cultivation (C)

According to the data over three seasons, contour cultivation improved crop growth and increased yield compared with downslope cultivation, although this difference was not significant. In 1999, with one exception for plant height, the higher values were always observed on the contour cultivation than downslope cultivation. On one occasion (40 DAS), significant difference ($F = 34.96$, $P < 0.01$) was found between them and there was ~10 cm height difference. The LAI followed the same pattern, except for the first measurement (20 DAS). Half of eight measurements did show significant differences between contour cultivation and downslope cultivation. In 2000, plants grew faster under contour cultivation than downslope cultivation at the early crop stage, but this advantage diminished at its maximum value. However, LAI was always greater on the contour cultivation treatment. In 2001, similar results were observed as 1999.

Yields obtained under contour cultivation did not have significant differences compared to downslope. However, there were consistent trends for increased yields with contour cultivation and planting, suggesting that the altered canopy architecture may have improved light interception, particularly in the earlier part of the season.

The contour cultivation may have also produced small (but not significant) improvements in soil properties.

Contour cultivation has the advantage of runoff and soil loss, nutrient retention and greater solar radiation penetration (Dong, 1993). The evaluation of treatments on runoff and soil loss was not available on the experimental plots. However, the effect of contour cultivation on runoff and soil loss is well documented (Narayana, 1987; MaIsaac *et al.*, 1990; Kukal *et al.*, 1993). In Yunnan, Barton (2000) found contour cultivation reduced soil erosion by 31% compared with downslope cultivation. Similar results were obtained by An (2002) and Milne (2001).

4.6 Economic returns of different treatments

Net return is the best index to evaluate different treatments in terms of economic benefits. The value depends on output and input. In this study, among the treatments, the lowest materials input and labour cost was D, but output was also the poorest, so the net return was the lowest over the three years. Only 2000 was an exception, it was better than C+P+IS because of the soybean failure. Usually the net income of C was better than D and lower than other treatments. The surprising result of 2000 showed C ranked second, just behind C+P. The net return of C+P was highest in both 1999 and 2000 and ranked second in 2001. This can be explained by higher output and medium inputs. The net income of C+P+IS relied strongly on the output of both maize and soybean yields. If there was no crop failure, it was usually a good return, such as in 1999 and 2001. However, if one of the crops failed, it was probably the poorest, for example in 2000, the soybean failed before harvest. The net return from C+P+S in 1999 was less than C+P, giving a substantially lower net return for this treatment. In 2000 and 2001, the output from C+P+S was higher than C+P, but insufficient to give a higher net return. Therefore C+P+S treatment could not be justified on the basis of the low economic return. The benefits of adding straw are much more related to improvement in soil conservation (Section 4.5.2) where the evidence from soil erosion plot studies is convincing. In order to recommend the use of straw a full cost-benefit analysis would have to be attempted on these soil conservation measures.

4.7 Limitations of the study

This experimental programme should be evaluated with in the context of the SHASEA Project, of which it forms a contribution. This developed from erosion plot studies at YAU and involved essentially larger scale evaluation of the selected practises. This required that the experiment had to be established on farmer's plots and managed as close to farmer practise as possible. Five treatments were selected in this research. Four conservation cultivation practises were selected to compare with traditional cultivation (downslope cultivation was commonly used by local farmers). However, the use of farmer's plots within the catchment did impose some limitations:

1) Plots were small and such plots may exaggerate edge effects. However, larger plot sizes and greater plot homogeneity could not be achieved within the conditions available within the catchment.
2) By design, the plots selected were farmer's plots in the catchment, with the possibility of varied and unknown histories.
3) For the first two years, the research relied on the weather station in the village, which was 500 m below the experimental site. Only by Year 3 was a fully operational Delta-T weather station available adjacent to the experimental plots. Therefore in Years 1 and 2, weather conditions had to be extrapolated cautiously in relation to the field plots.
4) The slopes of plots varied between 8-13°. Different slope gradients may have caused differences in water and nutrient distributions. However, slopes were selected for the most practical uniformity under field conditions and are representative of Yunnan upland agriculture. If it had been possible, larger plot sizes and more consistent gradients would have been chosen.
5) Plot management activities affected soil conditions. For example, many times it was necessary to enter plots for investigations, which would compact the soil and increase soil bulk density.
6) The evaluation of treatments in this study could have been improved if replication had been increased. A larger randomized block design with 4-5 replications would have been better, given the heterogeneity across the experimental area; but this was not possible for practical measures.
7) Use of the traditional 'pit' system for applying fertilizer and manure makes the analysis of general changes in soil nutrient levels more difficult to interpret.

4.8 Conclusions

Based on three years of field research, some conclusions can be obtained. Soil moisture and temperature are important to crop growth, especially in the early crop growth stage. There was a crucial time limiting crop growth in June 1999, when plants without mulch were withered by soil water deficiency during dry weather. Although watering could have replaced the soil moisture, crop growth was still affected, especially on the downslope cultivation with no mulch treatment.

The 1999 yields showed significant differences between treatments. The contour cultivation with mulch increased yields greatly compared to cultivation with no mulch (increased by 40.3-54% compared with downslope treatment). The possible reason was that mulching retained soil moisture during dry weather compared to no mulch. Then made plants grow fast and canopies develop well, so plants had a high ratio of photosynthesis and high final yields. The yields in 2000 showed apparent differences among treatments, contour cultivation with mulch increased yield by 18.6-24% compared by downslope treatments, although these differences were not significant at $P \leq 0.05$, when considering overall plot yields. However, when measured on plant basis, there were significant differences in plant height, GLAI, stem fresh weight, 1000 grains weight and grain yield. The extent of the improvement in yield in 2000 was less than in 1999; one possible reason for these differences was that rainfall was more evenly distributed in 2000, with no dry spells after planting, so the benefits of mulching in retaining soil moisture were less marked. Significant treatments differences were again found in 2001, even after a heavy hail on 9 August 2001 reduced final yields. Contour cultivation with polythene and intercropping soybean achieved the highest grain yield, then the treatment of contour cultivation with polythene and straw, then contour cultivation with polythene, followed by contour cultivation. The lowest was downslope cultivation.

All the original objectives for the study have been achieved. The main findings from the research are:

1) Both the total and the distribution of rainfall were different in the three years of the study. In 1999, although the total rainfall was high, the sporadic distribution

resulted in poor crop establishment. Rainfall in 2000 and 2001 was more evenly distributed and had less impact on crop development, limiting the magnitude of responses to cultivation treatments.

2) Effect of treatments on crop establishment and early vegetative growth were most marked when water availability was limited early in the season. In these circumstances, polythene mulch was beneficially used by increasing soil temperatures and retaining soil moisture. Straw mulch also retained soil moisture between the rows. This was most marked during early establishment in 1999.

3) Intercropping with soybean provided early canopy growth and increased surface cover, which could have improved soil conservation.

4) These effects of treatment on soil temperature and moisture were most marked early in the cropping season.

5) Changes in soil bulk density were mainly affected by amounts of disturbance rather than treatments.

6) Very few treatment effects were found relating to changes in soil chemical properties over three years. Probably the period may not have been sufficiently long to determine marked changes or any changes that might have occurred may have been masked by fertilizer and manure inputs. Despite these limitations, a few trends appeared from the data. After three years, contour cultivation plus polythene and straw gave an apparent increase in K.

7) Contour cultivation, contour cultivation with polythene, contour cultivation with polythene and straw mulch and contour cultivation with polythene and intercroppings can all increase maize yield, resulting from more rapid early growth and greater Green Leaf Area Index compared to downslope cultivation.

The highest economic return was obtained from the C+P treatment over three years. It is considered that the C+P+S technique could contribute towards sustainable agriculture, but the value of the straw has to be taken into account and return was lower compared with C+P. The technique could assist with long-term soil, water and nutrient conservation. Simply replacing downslope cultivation with contour cultivation can increase crop yields and improve economic return.

In short, it is imperative we study cropping treatments in real agricultural situations in collaboration with farmers. While controlled plot studies enable careful scientific evaluation, the applicability and overall effectiveness of the techniques are difficult to evaluate. Therefore, more holistic field studies can make an important contribution to the development of systems for improving the sustainability of agriculture. However, in simulating real agro-environmental conditions, achieving complete plot homogeneity is very difficult.

4.9 Suggestions for future research

Based on the findings and limitations, some suggestions are made for future research:

1) This study has shown contour cultivation with polythene to increase crop yields. However, the problems raised by the polythene are not fully explored. A further investigation about this 'white pollution' is necessary, together with the possible advantages of the double ridge system.

2) The high fertilizer input in this study may have diminished the difference of different treatments in relation to soil chemical properties. This fertilizer regime may not have been optimized. In future work, the fertilizer input should be taken into account.

3) Soil samples and analysis strategies need be improved. The results from three years showed the samples taken from different positions on such small plots were ineffective. Probably a larger plot (>50 m long) on the sloping land is required to monitor changes in distribution. Also the nutrients taken by the plants should be measured.

4) The soil bulk density measurement in this study was frequently disturbed. In order to evaluate treatment effects on soil bulk density, as they would occur in the actual field, the measurement location should not trampled when taking other

measurements.

5) Interesting and valuable results of soil temperature were recorded by the Delta T-logger, which connected with soil sensors on selected plots. However, all treatments should be monitored and repeated. These continuous readings could be used to help identify the causes for any significant differences in crop performance and yield between treatments. Furthermore, a model linking maize growth and yield and soil moisture and soil temperature could be built, but this needs to be extended over more years.

6) The soil profile moisture probe did not always produce consistent or meaningful results when the probe installed in the middle of each plot. Therefore, longer-term studies are advisable, with more access tubes in different locations.

7) A preliminary simple economic evaluation of different treatments was made in this study and very interesting results were produced. However, the cost of material transport was not included in this study, so these should be extended, giving more detailed cost-benefit evaluations.

8) The research findings should be demonstrated to farmers and developed as part of the local extension service. The success of sustainable agriculture relies on farmers, especially in China, where ~75% of the population is engaged in the agriculture. Training work also needs be taken at the same time. A number of these issues is being addressed by the SHASEA Project and follow-up measures. For the short term, increases in maize productivity (which is the main outcome of this research) recommended the use of contour cultivation with polythene mulch. However, for the long-term, contour cultivation combined with polythene and straw (INCOPLAST) or intercropping techniques are recommended, where improvements in soil conservation are particularly important.

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Appendix 1. Soil temperature measurements during the 1999 cropping season.

99 Soil temperature			Morning 0700-0800			Noon 1400-1500				Afternoon 1700-1800			
treatment	DAS	depth0	depth5	depth10	depth15	depth0	depth5	depth10	depth15	depth0	depth5	depth10	depth
D	20	18.6	18.4	19.0	19.7	31.0	30.6	27.0	23.6	30.1	30.2	28.2	27.1
D	20	18.8	18.0	19.0	19.9	30.5	29.1	26.8	24.5	30.8	31.3	29.0	27.2
D	20	21.0	18.9	19.6	19.9	33.3	29.5	26.9	24.1	27.7	27.5	26.2	24.8
C	20	19.0	18.1	18.8	19.8	31.5	29.4	27.2	25.0	31.1	31.5	29.1	26.6
C	20	18.9	18.4	19.2	19.8	30.4	28.4	26.2	23.9	30.5	29.1	27.9	25.7
C	20	18.8	18.6	18.9	19.6	32.7	26.9	25.2	23.0	27.8	28.2	26.8	25.7
C+P	20	20.0	20.4	21.8	22.5	38.1	32.5	29.0	25.6	36.7	32.8	30.0	27.3
C+P	20	20.0	19.9	20.6	21.5	34.9	30.7	28.1	26.0	34.6	32.2	29.0	26.1
C+P	20	19.8	20.3	21.2	21.7	37.9	31.8	28.0	26.3	34.0	33.5	30.4	27.9
C+P+S	20	18.8	20.0	20.8	22.4	37.0	30.9	26.8	25.0	35.3	32.5	29.4	25.7
C+P+S	20	19.4	20.2	20.7	21.4	35.7	30.7	27.3	25.2	34.9	31.5	29.0	26.6
C+P+S	20	19.8	20.9	21.4	21.8	34.9	30.5	27.8	25.2	33.6	30.7	27.9	26.5
C+P+IS	20	19.9	20.9	21.7	22.3	41.1	36.4	30.9	27.0	41.1	37.1	33.9	29.9
C+P+IS	20	19.6	20.9	21.7	22.3	38.9	32.4	29.3	26.4	35.8	33.0	29.5	27.9
C+P+IS	20	19.5	20.7	21.6	22.4	38.0	32.6	28.8	26.7	37.7	34.3	32.1	28.9
D	40	20.6	20.9	21.2	21.6	37.8	35.0	31.1	27.1	27.4	29.9	28.9	26.7
D	40	20.9	21.4	21.4	21.8	39.3	32.1	27.2	25.5	27.8	28.4	27.7	26.1
D	40	22.7	22.4	22.4	22.1	37.0	33.5	31.7	27.7	27.1	27.9	27.2	26.7
C	40	20.9	21.1	21.0	21.3	36.7	32.4	29.0	26.5	28.1	29.6	27.9	25.8
C	40	22.0	21.8	21.9	22.3	37.0	31.3	29.0	25.8	26.9	27.4	27.0	25.4
C	40	22.4	21.6	21.8	21.8	35.7	31.5	29.7	26.9	26.8	27.5	26.4	25.8
C+P	40	20.4	20.9	21.7	21.8	36.7	29.8	27.6	26.1	29.0	28.7	27.8	26.9
C+P	40	21.5	21.9	21.9	22.0	41.8	32.6	29.6	27.1	27.9	28.1	27.5	26.4
C+P	40	22.3	22.2	22.4	22.5	39.0	32.0	29.0	27.5	26.9	27.7	27.2	26.0
C+P+S	40	21.2	20.8	21.2	21.5	40.1	30.3	27.5	26.4	28.8	28.6	27.1	25.8
C+P+S	40	21.1	21.6	21.8	22.0	39.0	32.9	28.5	27.0	27.5	27.5	26.5	25.2
C+P+S	40	21.6	21.9	22.1	22.4	38.7	32.2	29.1	26.2	27.2	27.0	26.4	25.4
C+P+IS	40	21.2	21.6	22.1	22.9	40.3	33.1	29.7	27.2	30.5	31.2	29.8	27.6
C+P+IS	40	21.4	21.6	21.8	22.1	37.3	32.5	28.8	26.5	27.0	27.4	26.4	25.1
C+P+IS	40	22.6	22.2	22.5	22.7	38.3	32.7	29.8	26.8	28.8	28.3	27.5	26.7
D	60	18.5	18.8	19.3	19.5	28.3	26.5	23.7	22.0	23.9	23.6	22.4	20.9
C	60	18.2	19.0	19.3	19.2	28.5	24.8	22.1	20.2	24.7	23.8	22.1	21.1
C+P	60	18.9	19.0	19.3	19.8	30.5	25.4	22.7	20.9	26.3	25.7	24.0	22.4
C+P+S	60	19.1	19.6	19.7	19.6	27.9	25.3	23.1	20.9	24.1	23.0	22.0	20.9
C+P+IS	60	18.1	18.5	18.5	18.6	28.0	26.2	23.8	23.3	25.6	23.8	22.6	21.8
D	80	18.2	18.2	18.9	19.8	26.9	23.9	22.6	21.1	21.9	22.0	21.7	21.4
C	80	18.5	18.6	19.4	19.9	29.3	25.5	22.4	20.9	22.8	22.4	22.1	21.7
C+P	80	19.1	18.2	19.0	19.8	30.9	25.6	22.6	21.2	21.7	22.0	21.7	21.2
C+P+S	80	17.8	18.5	19.4	19.9	26.8	24.5	22.2	20.8	22.0	22.6	22.4	21.6
C+P+IS	80	17.6	18.1	19.0	19.8	24.8	23.6	22.1	20.7	21.4	22.4	22.2	21.7
D	100	17.6	18.3	18.6	18.8	20.9	20.0	19.8	19.2	20.7	20.0	19.9	19.7
C	100	17.8	18.5	18.6	18.9	20.6	19.8	19.3	19.1	20.0	20.0	19.8	19.5
C+P	100	17.4	17.9	18.2	18.2	20.2	19.4	19.0	19.3	19.6	19.2	19.3	19.1
C+P+S	100	18.0	18.5	18.8	19.0	20.3	19.5	19.1	19.3	20.0	19.9	19.7	19.6
C+P+IS	100	17.7	18.1	18.5	18.5	20.8	19.8	19.2	19.3	20.0	19.9	19.7	19.4
D	120	15.5	17.1	17.7	17.9	22.2	20.9	20.0	20.0	22.4	22.2	21.0	21.1
C	120	15.6	16.8	17.6	18.0	22.6	21.1	20.0	19.9	21.9	21.7	20.4	20.7
C+P	120	15.6	16.7	17.3	17.9	22.8	20.7	19.7	19.3	22.3	21.3	20.4	20.0
C+P+S	120	16.3	17.5	18.3	18.4	21.8	19.9	19.3	19.4	22.3	21.3	20.6	20.1
C+P+IS	120	16.3	17.4	18.1	18.3	23.0	20.5	19.7	19.5	23.7	22.3	20.9	20.2

Appendix 2. Soil moisture measurements during the 1999 cropping season.

treatment	DAS	5cm	10cm	15cm	Treatment	DAS	5cm	10cm	15cm
D	20	22.6	26.2	27.9	D	80	20.1	21.0	21.2
D	20	21.8	22.2	22.9	D	80	20.2	21.0	21.5
D	20	21.0	24.7	20.8	D	80	21.4	21.3	21.1
C	20	22.5	27.7	26.3	C	80	22.4	24.0	23.9
C	20	21.2	20.0	22.0	C	80	17.1	18.5	18.0
C	20	22.8	24.9	24.4	C	80	21.7	22.2	21.6
C+P	20	21.6	24.0	24.5	C+P	80	22.2	21.3	21.9
C+P	20	23.0	26.3	26.0	C+P	80	23.7	23.4	23.8
C+P	20	22.5	24.6	25.2	C+P	80	24.2	22.9	21.4
C+P+S	20	25.2	26.6	25.0	C+P+S	80	19.5	19.6	19.4
C+P+S	20	25.6	25.6	25.2	C+P+S	80	22.5	22.6	23.7
C+P+S	20	25.4	25.3	25.8	C+P+S	80	20.0	20.4	20.7
C+P+IS	20	22.4	25.1	24.7	C+P+IS	80	19.7	20.1	19.4
C+P+IS	20	25.3	24.5	26.0	C+P+IS	80	21.2	20.9	20.6
C+P+IS	20	19.9	22.7	23.8	C+P+IS	80	21.1	22.6	22.0
D	40	12.1	15.4	17.4	D	100	36.5	34.6	34.4
D	40	11.0	14.0	15.8	D	100	31.1	29.3	28.3
D	40	10.4	12.4	12.6	D	100	32.7	31.2	30.8
C	40	12.0	15.2	17.5	C	100	31.9	37.0	29.9
C	40	8.7	12.0	10.9	C	100	28.7	28.5	26.0
C	40	10.7	13.6	14.8	C	100	32.4	34.9	32.5
C+P	40	14.5	16.0	17.9	C+P	100	27.9	30.4	31.9
C+P	40	15.9	14.5	14.1	C+P	100	30.8	28.6	27.0
C+P	40	14.5	15.7	14.3	C+P	100	27.7	28.9	27.9
C+P+S	40	16.0	18.4	18.3	C+P+S	100	30.2	29.8	31.1
C+P+S	40	15.4	15.6	16.7	C+P+S	100	28.8	28.5	29.4
C+P+S	40	14.7	15.5	16.5	C+P+S	100	26.9	27.2	26.9
C+P+IS	40	14.9	15.5	15.7	C+P+IS	100	29.2	30.6	29.0
C+P+IS	40	17.1	14.9	15.5	C+P+IS	100	32.0	31.2	28.5
C+P+IS	40	13.7	14.8	15.5	C+P+IS	100	30.3	29.2	30.0
D	60	30.5	28.5	28.5	D	120	27.9	27.4	21.2
D	60	27.8	26.9	27.1	D	120	27.6	22.1	17.4
D	60	27.6	20.4	25.6	D	120	24.2	25.5	23.6
C	60	30.3	27.9	28.5	C	120	28.8	24.4	22.5
C	60	24.9	23.5	24.0	C	120	21.8	22.7	20.3
C	60	30.0	28.9	28.3	C	120	30.1	26.5	23.0
C+P	60	24.0	23.9	24.2	C+P	120	25.5	27.1	27.0
C+P	60	25.3	25.0	23.8	C+P	120	25.3	24.7	21.8
C+P	60	24.9	25.5	26.6	C+P	120	24.9	23.8	21.6
C+P+S	60	28.4	27.3	26.6	C+P+S	120	27.9	23.1	21.4
C+P+S	60	27.2	27.7	26.9	C+P+S	120	28.3	27.9	25.0
C+P+S	60	22.9	24.9	25.0	C+P+S	120	26.3	22.2	22.6
C+P+IS	60	23.2	22.7	23.4	C+P+IS	120	30.6	29.0	23.6
C+P+IS	60	27.9	27.8	26.2	C+P+IS	120	26.5	24.4	23.4
C+P+IS	60	24.8	25.9	25.7	C+P+IS	120	28.6	24.1	22.7

Appendix 3.Mean soil bulk density in 1999.

Beginning of the cropping season						Beginning of the cropping season									
10 cm						10 cm soil depth					20 cm soil depth				
Treatment	up	middle	bottom	mean		Treatment	up	middle	bottom	mean		up	middle	bottom	mean
D	1.03	1.11	1.14	1.09		D	1.36	1.32	1.34	1.34		1.38	1.27	1.23	1.29
D	1.02	1.29	1.29	1.20		D	1.31	1.40	1.43	1.38		1.31	1.59	1.47	1.46
D	1.06	1.26	1.31	1.21		D	1.46	1.48	1.4	1.45		1.31	1.26	1.37	1.31
C	1.08	1.16	1.02	1.09		C	1.36	1.38	1.37	1.37		1.32	1.41	1.39	1.37
C	1.53	1.29	1.27	1.36		C	1.41	1.29	1.19	1.30		1.54	1.38	1.34	1.42
C	1.08	1.16	1.20	1.15		C	1.44	1.34	1.44	1.41		1.46	1.38	1.35	1.4
C+P	1.25	1.35	1.31	1.30		C+P	1.39	1.46	1.26	1.37		1.34	1.22	1.32	1.29
C+P	1.16	1.22	1.25	1.21		C+P	1.33	1.40	1.29	1.34		1.37	-	1.39	1.38
C+P	1.06	1.16	1.21	1.14		C+P	1.38	1.47	1.44	1.43		1.28	1.39	1.36	1.34
C+P+S	1.33	1.15	1.20	1.23		C+P+S	1.29	1.34	1.31	1.31		1.32	1.29	1.33	1.31
C+P+S	1.16	1.04	1.42	1.21		C+P+S	1.41	1.48	1.50	1.46		1.25	1.38	1.52	1.38
C+P+S	1.33	1.34	1.15	1.27		C+P+S	1.12	1.40	1.36	1.29		1.36	1.44	1.36	1.39
C+P+S	1.30	1.21	1.16	1.22		C+P+S	1.38	1.24	1.38	1.33		1.3	1.34	1.31	1.32
C+P+S	1.26	1.18	1.20	1.21		C+P+S	1.32	1.58	1.5	1.47		1.27	1.31	1.35	1.31
C+P+S	1.20	1.31	1.23	1.25		C+P+S	1.46	1.66	1.26	1.46		1.35	1.34	1.56	1.42

Appendix 4. Mean soil chemical analysis before planting in 1999.

treatment	N%	Avail P (ppm)	K %	P %	O.M%	K (ppm)	Avail N (ppm)	pH
D(T)	0.24	14.23	0.98	0.03	1.03	66.44	131.19	4.90
D(T)	0.25	11.15	0.73	0.03	0.98	191.00	286.79	4.75
D(T)	0.28	23.59	0.42	0.04	1.08	155.00	246.25	4.95
C(T)	0.23	17.17	0.81	0.04	0.99	114.30	159.45	5.21
C(T)	0.24	23.23	0.85	0.05	0.95	153.80	186.71	5.30
C(T)	0.30	23.50	1.13	0.04	1.38	58.11	254.97	5.60
C+P(T)	0.40	12.15	1.62	0.03	1.21	93.60	217.86	5.17
C+P(T)	0.31	38.30	0.38	0.04	1.14	136.8	310.33	5.50
C+P(T)	0.25	20.31	1.02	0.04	1.04	157.10	127.50	5.40
C+P+S(T)	0.21	12.20	1.2	0.02	1.04	86.60	126.04	5.12
C+P+S(T)	0.29	40.97	0.74	0.05	1.22	80.34	308.45	5.32
C+P+S(T)	0.19	19.34	0.96	0.02	1.31	96.44	144.11	5.37
C+P+IS(T)	0.23	19.41	0.89	0.03	1.14	94.10	182.47	4.90
C+P+IS(T)	0.21	16.48	2.08	0.03	0.82	102.00	180.55	5.40
C+P+IS(T)	0.28	17.21	0.78	0.05	1.07	181.60	215.91	5.00
D(B)	0.20	16.28	1.35	0.03	0.91	56.50	148.62	5.10
D(B)	0.25	28.35	1.58	0.03	1.03	78.77	299.86	4.81
D(B)	0.26	37.82	0.29	0.05	1.26	131.20	205.56	5.40
C(B)	0.22	18.19	3.15	0.03	1.15	215.90	157.26	4.95
C(B)	0.26	19.42	0.48	0.05	1.31	137.90	229.46	5.20
C(B)	0.21	33.93	0.36	0.04	1.11	66.03	231.19	5.55
C+P(B)	0.28	13.34	1.15	0.04	1.30	90.53	192.28	5.18
C+P(B)	0.27	46.40	1.57	0.05	1.20	96.29	197.82	5.20
C+P(B)	0.23	31.83	0.99	0.05	1.01	146.70	171.12	5.60
C+P+S(B)	0.19	14.15	0.56	0.03	0.96	78.71	145.42	4.90
C+P+S(B)	0.29	22.65	0.29	0.04	0.93	66.41	209.10	5.60
C+P+S(B)	0.25	34.49	0.15	0.03	1.35	91.91	94.14	5.56
C+P+IS(B)	0.28	15.39	0.85	0.04	1.20	87.62	212.76	4.90
C+P+IS(B)	0.26	18.25	0.74	0.03	1.30	66.48	284.24	5.42
C+P+IS(B)	0.24	45.24	1.59	0.05	0.94	112.50	199.53	5.00
D(M)	0.25	13.20	1.65	0.03	1.01	60.55	213.72	5.00
D(M)	0.26	31.89	0.90	0.02	1.09	68.52	316.29	5.00
D(M)	0.26	30.86	0.81	0.04	1.32	133.30	212.95	5.22
C(M)	0.24	17.51	1.60	0.03	1.04	94.49	188.86	5.20
C(M)	0.26	24.55	1.22	0.04	1.13	160.00	212.05	5.18
C(M)	0.24	32.24	1.23	0.03	1.15	62.05	252.67	5.50
C+P(M)	0.25	16.20	1.52	0.04	1.28	86.18	179.33	5.00
C+P(M)	0.28	38.04	0.67	0.06	1.26	102.30	239.56	5.26
C+P(M)	0.26	36.11	1.23	0.05	1.24	166.9	249.03	5.14
C+P+S(M)	0.27	13.44	0.75	0.03	1.20	82.80	277.57	4.80
C+P+S(M)	0.27	23.57	1.30	0.05	1.23	78.04	219.73	5.45
C+P+S(M)	0.27	23.15	1.54	0.04	1.26	82.16	182.54	5.48
C+P+IS(M)	0.25	16.22	1.42	0.04	1.31	84.41	191.04	5.05
C+P+IS(M)	0.26	17.27	0.73	0.04	1.30	96.09	306.82	5.35
C+P+IS(M)	0.22	36.41	0.64	0.04	1.17	162.50	233.06	5.10

(T)- Samples from plot top position, (B)- Samples from plot bottom position and (M) Mixture plot samples

Appendix 5. Mean soil chemical analysis after harvesting in 1999.

Treatment	N%	Avail. P (ppm)	K %	P %	O.M %	K (ppm)	Avail. N (ppm)	pH
D(T)	0.24	17.9	0.72	0.03	1.14	46.39	181.59	4.88
D(T)	0.23	8.4	1.20	0.02	1.04	98.59	178.00	4.73
D(T)	0.23	6.1	1.18	0.03	1.40	141.60	164.57	4.91
C(T)	0.24	2.6	0.67	0.03	1.13	103.20	137.81	5.23
C(T)	0.26	7.5	1.88	0.04	1.55	151.20	256.25	5.26
C(T)	0.22	6.7	1.29	0.05	1.34	36.54	154.82	5.64
C+P(T)	0.30	3.2	0.73	0.03	1.34	103.70	108.31	5.15
C+P(T)	0.30	12.0	0.81	0.03	1.56	130.30	265.57	5.56
C+P(T)	0.17	6.1	0.70	0.04	1.29	100.70	165.93	5.41
C+P+S(T)	0.22	3.2	0.36	0.04	1.18	78.26	144.90	5.19
C+P+S(T)	0.26	6.7	0.36	0.02	1.33	80.06	181.67	5.30
C+P+S(T)	0.20	4.7	1.32	0.03	1.06	68.34	175.12	5.36
C+P+IS(T)	0.28	3.6	0.73	0.04	1.43	100.20	197.74	4.87
C+P+IS(T)	0.25	4.8	0.49	0.04	1.20	110.00	166.47	5.38
C+P+IS(T)	0.17	4.1	0.42	0.01	1.35	96.50	196.18	5.06
D(B)	0.25	5.1	0.65	0.06	0.91	56.25	199.83	5.07
D(B)	0.26	17.4	0.80	0.02	1.17	101.60	142.66	4.74
D(B)	0.24	7.1	1.25	0.03	1.43	89.67	161.07	5.37
C(B)	0.24	6.1	0.19	0.03	1.45	67.92	144.25	4.95
C(B)	0.25	4.7	1.93	0.02	1.45	112.20	225.37	5.20
C(B)	0.26	12.9	1.12	0.05	1.36	66.45	158.76	5.54
C+P(B)	0.24	3.6	0.90	0.02	1.03	60.19	119.61	5.19
C+P(B)	0.25	9.2	1.07	0.03	1.13	68.15	215.59	5.18
C+P(B)	0.17	8.1	0.43	0.04	1.09	66.15	136.68	5.56
C+P+S(B)	0.22	3.6	0.99	0.04	1.33	84.68	149.59	4.78
C+P+S(B)	0.30	12.0	0.67	0.02	1.46	78.17	181.94	5.51
C+P+S(B)	0.24	10.0	1.37	0.03	1.200	50.61	206.46	5.52
C+P+IS(B)	0.29	5.6	1.01	0.04	1.35	66.40	193.62	4.85
C+P+IS(B)	0.25	8.1	1.73	0.04	1.39	97.78	211.58	5.42
C+P+IS(B)	0.19	16.1	0.55	0.03	1.27	86.53	136.49	5.03
D(M)	0.25	4.1	0.92	0.02	1.16	64.74	187.38	4.95
D(M)	0.24	10.0	1.20	0.02	1.16	82.15	129.03	5.02
D(M)	0.21	8.2	1.34	0.03	1.26	104.40	139.79	5.19
C(M)	0.25	3.4	0.59	0.03	1.13	148.70	146.02	5.19
C(M)	0.22	6.5	2.25	0.03	1.38	126.20	161.17	5.19
C(M)	0.22	10.3	1.30	0.04	1.37	48.28	165.52	5.49
C+P(M)	0.27	5.3	1.00	0.03	1.19	62.61	177.36	4.97
C+P(M)	0.26	14.5	1.70	0.03	1.34	64.46	202.68	5.27
C+P(M)	0.22	9.6	1.47	0.03	1.38	116.40	174.36	5.13
C+P+S(M)	0.24	3.6	0.71	0.04	1.27	76.36	164.00	4.87
C+P+S(M)	0.24	7.1	0.89	0.03	1.33	93.73	156.53	5.43
C+P+S(M)	0.25	3.7	1.59	0.03	1.31	78.96	207.96	5.45
C+P+IS(M)	0.26	3.2	0.92	0.05	1.28	93.39	198.76	5.05
C+P+IS(M)	0.25	12.6	1.31	0.04	1.31	80.53	159.00	5.35
C+P+IS(M)	0.25	6.1	0.23	0.03	1.30	96.04	152.18	5.11

(T)- Samples from plot top position, (B)- Samples from plot bottom position and (M) Mixture plot samples

Appendix 6. Mean plant height measurements during the 1999 cropping season.

Treatment	20d	40d	55d	70d	85d	100d	115d	130d
D	24.8	76.6	110.3	156.3	191.0	187.2	186.1	187.6
D	26.7	62.4	99.4	148.1	179.3	182.3	181.8	183.1
D	25.8	76.8	115.7	161.9	199.5	197.8	197.1	192.4
C	22.8	75.3	112.2	155.9	187.2	188.3	188.5	188.1
C	27.5	84.0	126.4	177.1	200.6	198.9	201.1	203.0
C	28.1	85.8	118.9	174.7	193.3	196.1	195.3	196.5
C+P	28.0	105.0	163.1	217.1	225.1	221.6	219.4	222.5
C+P	32.0	107.8	161.2	191.8	219.3	220.8	216.5	219.1
C+P	25.2	109.9	168.2	218.8	221.5	221.8	218	209.4
C+P+S	32.0	103.6	152.2	204.1	218.6	215.7	213.8	217.4
C+P+S	29.4	107.1	170.8	222.1	231.4	232.1	233.9	228.4
C+P+S	26.8	104.6	169.2	217.5	228.2	228.8	232.0	225.6
C+P+IS	28.2	105.4	154.9	211.6	211.5	211.5	209.8	213.8
C+P+IS	29.7	106.2	166.3	220.8	225.9	223.8	223.1	224.8
C+P+IS	30.6	102.1	152.4	206.2	212.5	213.4	214.6	212.0

Appendix 7. Mean Green Leaf Area Index during the 1999 cropping season.

treatment	20d	40d	55d	70d	85d	100d	115d	130d
D	0.04	0.50	1.65	2.43	2.49	2.43	2.19	1.83
D	0.05	0.32	1.24	1.92	2.15	2.00	1.93	1.61
D	0.04	0.50	1.68	2.55	2.54	2.40	2.22	1.89
C	0.04	0.49	1.71	2.68	2.42	2.62	2.44	1.89
C	0.04	0.58	2.12	2.97	2.78	2.77	2.54	2.11
C	0.04	0.63	1.96	2.84	2.48	2.55	2.42	1.64
C+P	0.06	1.34	3.17	4.02	3.77	3.87	3.55	2.78
C+P	0.08	1.22	3.14	3.72	3.49	3.45	3.11	2.35
C+P	0.05	1.36	3.45	4.29	4.15	3.98	3.16	3.22
C+P+S	0.07	1.17	2.85	3.64	3.54	3.63	3.38	2.64
C+P+S	0.06	1.27	3.25	4.05	3.99	3.88	3.63	2.45
C+P+S	0.04	1.11	2.99	3.92	3.83	3.81	3.58	3.06
C+P+IS	0.07	1.19	2.75	3.62	3.64	3.42	3.15	1.86
C+P+IS	0.07	1.13	2.98	3.67	3.47	3.49	3.13	2.58
C+P+IS	0.06	1.15	2.91	3.48	3.49	3.35	2.98	2.46

Appendix 8. Mean harvest parameters in 1999.

Treatment	Stem girth (cm)	Cob length (cm)	Cob girth (cm)	W. fresh cob (g)	W.fresh stem (g)	Grain number of two rows	W. dry cob (g)	W. dry stem (g)	W. dry grain (g)	1000 .W (g)	Yield1 (kg/ha)	Yield2 (kg/ha)	Plot stem (T/ha)
D	5.2	21.8	15.7	227.0	210.6	57	121.1	72.9	98.8	277.5	6990.0	6773.1	17.2
D	5.2	19.0	15.6	222.6	246.3	57	115.5	65.8	95.1	291.6	6593.0	6519.5	17.2
D	5.7	23.0	16.2	282.2	273.2	63	153.1	82.0	126.3	312.1	8203.0	8658.3	18.6
C	5.7	23.1	16.1	277.6	287.4	67	149.6	88.8	123.6	300.4	8220.0	8473.2	19.2
C	5.5	22.9	15.7	262.5	261.6	65	142.7	88.0	117.7	306.2	7493.0	8068.8	15.8
C	5.7	20.5	16.1	294.4	305.7	67	165.1	89.5	136.7	330.3	8497.0	9371.3	20.4
C+P	6.3	20.4	16.7	337.7	402.0	69	199.5	127.4	174.3	316.7	11193.0	11948.9	21.3
C+P	6.8	20.6	17.1	337.9	349.7	70	191.4	116.5	158.9	312.7	10523.0	10893.2	23.2
C+P	6.8	21.2	17.3	371.6	450.4	73	218.2	137.8	181.7	347.2	11743.0	12456.2	26.8
C+P+S	6.7	22.9	16.7	327.9	369.3	75	184.2	117.6	152.9	309.1	9163.0	10481.9	21.1
C+P+S	6.1	20.8	16.6	345.9	365.3	71	199.8	128.3	160.8	312.3	11207.0	11023.5	25.2
C+P+S	6.3	23.8	16.7	350.3	463.0	70	197.1	125.5	163.0	315.4	11997.0	11174.3	30.5
C+P+IS	6.3	19.7	17.4	282.8	297.0	67	168.1	106.0	139.1	314.7	9423.0	9535.8	18.5
C+P+IS	5.8	21.0	16.4	313.9	321.8	67	181.8	111.0	150.1	336.7	10777.0	10289.9	22.0
C+P+IS	6.3	23.2	16.4	320.6	343.0	73	185.5	98.7	155.3	317.2	10373.0	10646.4	23.1

Appendix 9 Mean soil temperature at the soil surface during the 2000 cropping season.

DAS	20	27	38	52	66	80	94	108	122
D	18.4	24.2	22.1	18.2	21.4	20.5	23.6	19.9	17.1
D	18.7	24.9	21.7	18.4	21.7	19.5	23.7	19.9	17.5
D	19.2	25.3	22.6	18.7	21.7	22.4	22.3	19.7	18.6
C	18.3	22.1	21.2	17.7	21.1	19.6	23.6	19.9	16.9
C	19.2	24.2	21.9	18.8	23.1	23.0	23.2	20.8	18.4
C	17.9	24.2	21.6	18.9	22.1	21.4	22.7	19.9	17.5
C+P	20.1	32.7	23.4	19.6	21.3	20.6	24.1	20.8	17.1
C+P	20.2	28.1	21.8	18.7	21.1	20.0	23.4	20.1	16.5
C+P	21.0	27.5	24.0	18.9	22	23.1	22.5	20.0	17.8
C+P+S(P)	20.4	29.6	23.6	19.2	22.1	20.7	24.2	21.4	17.2
C+P+S(P)	21.0	27.0	22.7	19.1	21.7	20.3	23.6	20.6	17.5
C+P+S(P)	20.0	28.1	23.4	19.0	22.4	20.7	22.7	20.3	17.3
C+P+S(S)	18.1	21.9	21.4	18.4	20.2	19.7	22.7	20.2	16.4
C+P+S(S)	17.9	20.1	21.6	18.9	20.9	20.3	22.4	20.0	16.7
C+P+S(S)	19.1	20.6	21.2	18.8	21.2	20.4	22.2	19.6	16.8
C+P+IS	21.7	35.4	24.5	19.5	21.2	21.2	24.2	22.2	17.5
C+P+IS	21.3	34.6	23.8	19.3	21.6	20.6	23.0	21.5	17.4
C+P+IS	21.5	33.4	23.6	19.0	22.8	22.6	23.2	20.7	20.0

Appendix 10. Mean soil temperature at 5 cm soil depth during the 2000 cropping season.

DAS	8	20	27	38	52	66	80	94	108	122
D	21.7	19.0	20.4	21.7	18.0	21.1	20.5	22.6	19.7	16.0
D	21.0	18.8	22.1	22.1	18.4	21.1	20.2	22.6	19.8	16.1
D	22.2	19.5	21.9	21.9	19.1	21.2	21.5	21.9	19.4	17.0
C	21.1	19.0	18.9	21.3	18.0	20.9	20.0	22.6	19.7	16.1
C	22.0	19.5	20.4	21.8	19.0	22.0	20.9	22.6	20.4	16.4
C	20.7	19.1	21.5	21.7	19.1	21.3	20.9	22.1	19.7	16.0
C+P	22.9	20.7	24.2	23.2	19.4	20.9	20.2	23.0	20.5	16.6
C+P	22.0	20.3	22.6	21.9	18.7	20.9	23.5	22.3	19.8	16.0
C+P	23.7	21.1	22.3	23.5	19.0	21.3	22.2	21.9	19.8	16.4
C+P+S(P)	23.2	20.5	25.2	22.7	19.4	20.8	19.8	23.1	21.4	16.5
C+P+S(P)	21.8	20.4	22.0	22.5	18.9	21.1	20.6	22.7	20.0	16.5
C+P+S(P)	23.0	20.4	22.7	23.5	19.1	21.5	20.5	22.3	19.9	16.4
C+P+S(S)	20.5	18.8	19.7	21.8	19.3	20.0	19.6	22.1	19.8	16.3
C+P+S(S)	20.6	18.5	18.3	21.6	19.1	20.7	20.7	21.8	19.9	16.2
C+P+S(S)	21.3	19.1	18.3	21.2	18.9	20.9	20.4	21.8	19.5	16.3
C+P+IS	25.2	22.3	31.9	24.4	20.0	21.2	21.1	23.6	22.4	17.2
C+P+IS	22.5	21.5	28.7	24.0	19.9	21.0	21.0	22.7	21.5	16.4
C+P+IS	23.1	21.5	28.6	23.8	19.6	22.2	21.9	22.7	20.7	18.4

Appendix 11 Mean soil moisture at 6 cm soil depth during the 2000 cropping season.

DAS	8	20	27	38	52	66	80	94	108	122	Mean
D	0.288	0.208	0.313	0.106	0.341	0.313	0.346	0.384	0.211	0.349	0.290
D	0.265	0.229	0.249	0.094	0.292	0.280	0.362	0.367	0.102	0.313	0.260
D	0.247	0.168	0.308	0.162	0.303	0.193	0.329	0.369	0.175	0.293	0.250
mean	0.267	0.202	0.290	0.121	0.312	0.262	0.346	0.373	0.163	0.319	0.270
C	0.249	0.190	0.308	0.119	0.336	0.255	0.346	0.362	0.213	0.285	0.270
C	0.227	0.147	0.316	0.107	0.300	0.216	0.338	0.328	0.172	0.292	0.240
C	0.265	0.162	0.326	0.112	0.285	0.257	0.356	0.366	0.134	0.269	0.250
mean	0.247	0.166	0.317	0.113	0.307	0.243	0.346	0.352	0.173	0.282	0.250
C+P(N)				0.216	0.333	0.356	0.328	0.236	0.119	0.241	0.260
C+P(N)				0.198	0.267	0.242	0.259	0.203	0.132	0.244	0.220
C+P(N)				0.270	0.269	0.278	0.313	0.334	0.186	0.223	0.270
mean				0.228	0.289	0.292	0.300	0.258	0.146	0.236	0.250
C+P(P)	0.028	0.074	0.209	0.112	0.091	0.158	0.185	0.158	0.188	0.153	0.140
C+P(P)	0.216	0.068	0.239	0.137	0.186	0.147	0.298	0.188	0.237	0.185	0.190
C+P(P)	0.093	0.063	0.234	0.170	0.175	0.175	0.298	0.239	0.173	0.091	0.170
mean	0.112	0.068	0.227	0.140	0.151	0.160	0.260	0.195	0.200	0.143	0.170
C+P+S(N)				0.280	0.348	0.343	0.280	0.176	0.168	0.254	0.260
C+P+S(N)				0.214	0.162	0.290	0.320	0.178	0.139	0.320	0.230
C+P+S(N)				0.211	0.252	0.303	0.290	0.204	0.175	0.310	0.250
mean				0.235	0.254	0.312	0.297	0.186	0.161	0.294	0.250
C+P+S(P)	0.060	0.079	0.191	0.088	0.282	0.348	0.190	0.285	0.185	0.119	0.180
C+P+S(P)	0.152	0.051	0.267	0.119	0.106	0.150	0.219	0.223	0.170	0.244	0.170
C+P+S(P)	0.060	0.056	0.195	0.163	0.287	0.175	0.176	0.165	0.198	0.168	0.160
mean	0.090	0.062	0.218	0.123	0.225	0.224	0.195	0.224	0.184	0.177	0.170
C+P+S(S)	0.262	0.315	0.336	0.357	0.380	0.369	0.384	0.346	0.395	0.359	0.350
C+P+S(S)	0.305	0.328	0.369	0.331	0.361	0.376	0.384	0.382	0.362	0.325	0.350
C+P+S(S)	0.308	0.274	0.372	0.310	0.315	0.323	0.390	0.344	0.361	0.280	0.330
mean	0.292	0.305	0.359	0.333	0.352	0.356	0.386	0.357	0.373	0.321	0.340
C+P+IS(N)				0.272	0.339	0.320	0.282	0.382	0.208	0.269	0.300
C+P+IS(N)				0.344	0.223	0.329	0.295	0.264	0.157	0.343	0.280
C+P+IS(N)				0.255	0.287	0.336	0.254	0.204	0.145	0.290	0.250
mean				0.291	0.283	0.328	0.277	0.283	0.170	0.300	0.280
C+P+IS(P)	0.061	0.035	0.200	0.221	0.043	0.213	0.208	0.287	0.297	0.292	0.190
C+P+IS(P)	0.050	0.058	0.084	0.219	0.104	0.132	0.145	0.160	0.157	0.237	0.130
C+P+IS(P)	0.099	0.015	0.195	0.172	0.173	0.162	0.186	0.162	0.208	0.341	0.170
mean	0.070	0.036	0.159	0.204	0.107	0.169	0.180	0.203	0.220	0.290	0.160

(N)-near the plant base, (P)- under the polythene

Appendix 12 . Mean soil bulk density at the beginning and end of the 2000 cropping season.

At the beginning of the cropping			At the end of the cropping season		
Treatment	10cm	20cm	Treatment	10cm	20cm
D	1.27	1.42	D	1.33	1.22
D	1.27	1.29	D	1.31	1.30
D	1.25	1.23	D	1.25	1.28
C	1.38	1.37	C	1.23	1.23
C	1.28	1.20	C	1.30	1.25
C	1.35	1.24	C	1.33	1.28
C+P	1.26	1.36	C+P	1.29	1.15
C+P	1.25	1.24	C+P	1.21	1.12
C+P	1.18	1.22	C+P	1.22	1.27
C+P+S	1.24	1.33	C+P+S	1.22	1.22
C+P+S	1.20	1.33	C+P+S	1.23	1.20
C+P+S	1.25	1.39	C+P+S	1.28	1.20
C+P+IS	1.20	1.38	C+P+IS	0.99	1.31
C+P+IS	1.19	1.35	C+P+IS	1.02	1.22
C+P+IS	1.19	1.30	C+P+IS	1.07	1.23

Appendix 13. Mean soil chemical analysis before planting in 2000.

Treatment	N %	Avail. P (ppm)	Total K (%)	Total P (%)	O.M %	Avail.K (ppm)	Avail.N (ppm)	pH
D(T)	0.08	4.96	1.59	0.015	1.35	61.93	165.00	4.85
D(T)	0.11	4.60	2.36	0.018	1.48	82.21	139.50	5.16
D(T)	0.07	7.36	2.35	0.025	1.34	62.81	178.00	5.26
C(T)	0.10	3.64	2.42	0.009	1.20	71.43	157.70	5.11
C(T)	0.08	10.08	3.41	0.028	1.28	31.71	173.10	5.82
C(T)	0.06	4.05	1.13	0.023	0.96	81.99	156.10	5.01
C+P(T)	0.10	10.89	2.50	0.019	1.22	101.95	168.00	5.48
C+P(T)	0.08	9.99	0.67	0.006	1.07	81.71	235.90	5.42
C+P(T)	0.08	7.27	1.66	0.023	0.93	68.77	66.20	5.51
C+P+S(T)	0.07	9.28	1.73	0.023	0.97	126.27	189.10	5.43
C+P+S(T)	0.08	7.46	1.31	0.005	1.21	73.89	156.40	5.46
C+P+S(T)	0.12	6.48	1.03	0.032	1.23	49.58	118.50	5.10
C+P+IS(T)	0.09	4.22	1.47	0.010	1.14	107.60	175.50	5.48
C+P+IS(T)	0.08	10.29	1.31	0.010	1.15	65.40	164.00	4.96
C+P+IS(T)	0.08	4.09	2.22	0.027	1.16	61.93	217.50	5.67
D(B)	0.09	4.09	1.62	0.017	1.13	55.46	173.10	4.74
D(B)	0.09	6.94	1.17	0.015	1.46	59.68	156.10	5.21
D(B)	0.15	6.21	3.61	0.027	1.32	34.34	148.20	5.09
C(B)	0.06	5.50	0.67	0.013	1.35	76.58	182.70	5.03
C(B)	0.07	11.48	3.11	0.028	1.19	28.69	191.10	5.25
C(B)	0.08	5.19	1.06	0.028	1.06	56.73	187.20	4.68
C+P(B)	0.07	4.31	1.68	0.019	1.18	69.41	121.30	5.21
C+P(B)	0.09	5.39	0.75	0.017	1.10	48.77	146.30	5.64
C+P(B)	0.09	11.77	0.39	0.027	1.18	39.97	149.50	5.40
C+P+S(B)	0.10	3.52	1.45	0.004	1.36	76.69	182.30	5.55
C+P+S(B)	0.09	8.67	1.45	0.020	1.33	53.25	72.40	5.32
C+P+S(B)	0.08	10.91	0.89	0.024	1.03	45.93	190.10	5.14
C+P+IS(B)	0.06	4.70	1.59	0.017	1.04	80.19	172.00	5.05
C+P+IS(B)	0.12	6.58	0.82	0.011	1.19	50.14	194.50	5.20
C+P+IS(B)	0.09	14.00	1.62	0.028	1.16	85.48	206.80	5.48
D(M)	0.09	7.38	1.76	0.004	0.95	54.04	175.60	4.92
D(M)	0.10	8.41	2.00	0.016	1.51	77.11	181.10	5.07
D(M)	0.06	9.88	3.82	0.026	1.35	54.97	174.20	5.19
C(M)	0.09	6.07	1.80	0.018	1.26	79.72	195.70	5.29
C(M)	0.07	14.87	3.14	0.029	1.09	28.97	197.60	5.36
C(M)	0.11	5.51	0.92	0.025	1.19	62.43	148.70	4.88
C+P(M)	0.09	4.65	1.97	0.020	1.08	76.90	177.00	5.32
C+P(M)	0.10	16.89	1.06	0.015	1.27	62.01	206.10	5.70
C+P(M)	0.09	7.84	0.60	0.024	1.16	57.67		5.53
C+P+S(M)	0.07	4.60	1.34	0.016	1.17	83.79	137.20	5.53
C+P+S(M)	0.08	8.88	0.67	0.011	1.41	54.77	200.30	5.43
C+P+S(M)	0.09	6.68	0.53	0.024	1.28	101.28	105.60	5.23
C+P+IS(M)	0.08	3.46	2.50	0.019	0.99	85.53	148.00	5.20
C+P+IS(M)	0.09	7.38	1.38	0.024	1.30	50.55	204.30	5.35
C+P+IS(M)	0.09	6.13	0.53	0.028	1.21	65.43	181.20	5.58

(T)- Samples from plot top position, (B)- Samples from plot bottom position and (M) Mixture plot samples

Appendix 14. Mean soil chemical analysis after harvesting in 2000.

Treatment	N %	Avail. P (ppm)	Total K (%)	Total P (%)	O.M %	Avail. K (ppm)	Avail. N (ppm)	pH
D(T)	0.05	3.40	2.15	0.025	1.12	50.00	133.90	5.01
D(T)	0.09	2.85	3.19	0.017	0.96	93.95	143.60	5.29
D(T)	0.09	4.89	2.04	0.010	0.98	116.14	154.80	5.36
C(T)	0.07	4.19	3.02	0.018	1.08	57.01	147.10	5.23
C(T)	0.07	6.49	2.14	0.010	0.97	64.96	135.80	5.32
C(T)	0.06	2.99	3.08	0.020	0.77	145.91	114.30	5.04
C+P(T)	0.09	4.00	3.59	0.025	1.24	65.99	90.70	5.31
C+P(T)	0.09	4.70	2.99	0.020	1.20	95.45	121.90	5.34
C+P(T)	0.09	5.40	2.38	0.015	1.15	124.88	153.10	5.37
C+P+S(T)	0.07	4.05	1.38	0.017	0.49	91.87	186.50	5.70
C+P+S(T)	0.08	7.70	3.49	0.021	1.05	77.98	137.00	5.51
C+P+S(T)	0.16	3.50	2.81	0.016	1.13	89.95	89.00	5.42
C+P+IS(T)	0.10	1.70	2.83	0.022	1.13	65.95	116.70	5.62
C+P+IS(T)	0.09	3.29	3.06	0.017	0.89	47.96	57.20	4.71
C+P+IS(T)	0.09	1.60	2.81	0.018	0.97	146.00	173.50	5.78
D(B)	0.08	3.19	2.29	0.018	1.07	49.98	146.00	4.91
D(B)	0.07	6.29	1.74	0.021	0.89	53.98	232.50	5.10
D(B)	0.17	6.39	2.68	0.008	1.19	67.93	144.20	5.33
C(B)	0.14	3.00	2.59	0.016	1.09	67.99	145.30	5.21
C(B)	0.03	6.10	2.34	0.013	1.03	57.99	133.70	5.29
C(B)	0.09	4.80	2.48	0.024	1.16	87.91	133.40	4.98
C+P(B)	0.07	2.70	3.18	0.029	0.95	56.03	153.90	5.29
C+P(B)	0.09	7.50	2.10	0.017	1.10	41.92	161.60	5.40
C+P(B)	0.10	8.59	1.94	0.009	1.24	99.96	200.90	5.46
C+P+S(B)	0.02	1.90	2.91	0.022	1.08	63.90	134.10	5.46
C+P+S(B)	0.02	5.19	2.68	0.021	1.29	37.97	155.10	5.41
C+P+S(B)	0.07	4.79	2.04	0.015	1.27	73.85	84.30	5.39
C+P+IS(B)	0.10	2.79	2.90	0.021	1.10	87.84	177.10	5.22
C+P+IS(B)	0.10	4.24	2.39	0.021	1.27	69.98	161.60	5.43
C+P+IS(B)	0.04	11.28	2.33	0.019	1.01	71.91	127.40	5.70
D(M)	0.07	5.79	2.14	0.025	1.04	49.97	98.60	4.95
D(M)	0.03	4.80	2.59	0.022	1.13	57.97	217.10	5.47
D(M)	0.07	4.38	2.84	0.007	1.14	87.89	77.70	5.29
C(M)	0.11	3.09	2.50	0.018	1.28	57.94	134.10	5.11
C(M)	0.07	9.27	2.51	0.014	0.99	56.04	193.70	5.55
C(M)	0.10	4.70	2.63	0.024	1.11	133.76	81.00	4.70
C+P(M)	0.12	4.28	2.59	0.018	1.27	62.04	144.90	5.36
C+P(M)	0.11	9.27	2.89	0.028	1.31	75.91	166.40	5.64
C+P(M)	0.08	4.48	2.23	0.011	0.98	45.92	152.30	5.59
C+P+S(M)	0.07	4.00	2.84	0.023	1.03	76.00	169.30	5.45
C+P+S(M)	0.06	7.30	2.70	0.029	1.24	43.96	74.10	5.29
C+P+S(M)	0.12	3.69	2.19	0.020	1.15	71.94	117.20	5.23
C+P+IS(M)	0.12	4.80	3.03	0.026	1.11	67.98	172.70	5.08
C+P+IS(M)	0.10	4.40	2.44	0.018	1.31	83.85	136.10	5.26
C+P+IS(M)	0.11	4.35	2.06	0.013	1.19	93.86	156.40	5.64

(T)- Samples from plot top position, (B)- Samples from plot bottom position and (M) Mixture plot samples

Appendix 15. Mean plant height measurements during the 2000 cropping season.

Treatment	40D	55D	70D	85D	100D
D	55.3	106.8	146.1	201.9	223.1
D	57.0	98.1	137.4	191.4	218.4
D	65.3	108.6	144.4	197.5	209.4
C	66.6	109.5	151.1	196.8	216.0
C	65.5	111.9	155.5	200.4	219.8
C	66.9	108.6	145.8	192.6	210.0
C+P	73.8	126.9	174.8	224.5	234.9
C+P	86.3	140.4	183.9	219.1	226.9
C+P	69.5	122.8	171.0	222.0	227.1
C+P+S	86.8	139.9	174.6	219.6	217.1
C+P+S	82.3	141.3	185.4	218.6	229.9
C+P+S	75.1	134.9	183.1	223.4	223.9
C+P+IS	72.4	126.4	170.4	215.4	217.1
C+P+IS	85.3	143.8	187.3	228.9	231.1
C+P+IS	83.3	135.7	181.9	229.9	234.3

Appendix 16. Mean Green Leaf Area Index during 2000 cropping season.

Treatment	40D	55D	70D	85D	100D	115D	130D
D	0.20	1.21	2.50	3.42	3.75	3.61	3.01
D	0.23	1.00	2.44	3.24	3.65	3.45	3.18
D	0.31	1.31	2.56	3.73	3.58	3.41	3.31
C	0.34	1.36	2.82	3.82	3.72	3.52	3.75
C	0.25	1.37	3.18	3.94	4.09	3.85	3.42
C	0.35	1.39	2.80	3.80	3.72	3.42	3.09
C+P	0.45	1.92	3.48	4.45	4.29	4.02	3.57
C+P	0.70	2.84	3.86	4.28	4.35	4.17	3.73
C+P	0.42	1.73	3.06	3.89	4.15	3.92	3.77
C+P+S	0.64	2.60	3.94	4.61	4.39	4.16	3.22
C+P+S	0.54	2.45	3.93	4.21	4.43	4.21	3.62
C+P+S	0.51	2.06	3.40	4.19	4.19	3.87	3.62
C+P+IS	0.49	1.94	3.40	3.93	3.87	3.68	3.10
C+P+IS	0.66	2.38	3.78	4.27	4.23	3.79	3.27
C+P+IS	0.56	2.08	3.53	4.30	4.21	3.72	3.43

Appendix 17. Mean harvest parameters in 2000

Treatment	Stem Girth (cm)	Cob Length (cm)	Cob Girth (cm)	W. Fresh cob (g)	W. Fresh stem (g)	Grain no. of two columns	W. Dry stem (g)	W. Dry cob (g)	W. Dry grain (g)	W. 1000grain (g)	Yield1 (kg/ha)	Yield2 (kg/ha)	Leaf stem (T)
D	5.8	15.3	15.9	266.4	343.8	63.6	104.1	136.2	109.5	230.8	7556.8	7509.7	22.9
D	6.0	16.4	16.3	292.7	349.9	67.1	113.5	159.9	128.8	256.0	7199.8	8826.7	19.3
D	5.7	16.3	16.1	276.5	301.2	69.0	93.6	148.7	121.1	261.8	8703.1	8302.9	24.4
C	5.9	17.4	16.5	308.4	364.5	75.7	116.0	174.2	144.0	273.7	10050.7	9869.4	26.4
C	5.9	17.6	16.2	325.1	366.1	71.1	110.1	176.5	144.3	271.9	8303.7	9894.1	21.5
C	6.5	17.4	16.7	314.2	468.1	70.8	142.4	165.6	133.2	261.4	8086.0	9130.4	24.3
C+P	6.5	17.6	16.3	324.2	418.8	74.1	140.6	182.9	148.2	317.3	9164.5	10156.7	22.8
C+P	6.8	17.8	16.9	336.2	418.6	74.3	132.4	194.5	162.9	295.5	9834.2	11169.3	23.8
C+P	6.4	16.6	16.6	302.2	403.2	69.0	113.2	164.4	135.5	272.4	9478.9	9287.4	28.9
C+P+S	6.9	18.2	17.0	364.1	453.6	75.0	147.5	204.5	165.6	292.8	8087.3	11355.7	21.4
C+P+S	6.8	18.1	16.8	362.9	369.7	74.5	129.6	210.0	173.6	301.8	10559.3	11898.7	25.0
C+P+S	6.6	17.1	16.5	317.5	393.0	70.0	119.6	179.1	149.2	289.7	10452.6	10231.4	27.8
C+P+IS	6.4	17.1	16.7	353.9	393.2	65.7	125.0	185.5	150.6	318.4	7844.4	10326.7	19.9
C+P+IS	6.4	17.4	16.8	316.8	350.2	69.6	118.9	182.7	151.9	289.6	10474.3	10415.1	26.1
C+P+IS	6.5	17.7	16.5	340.2	381.6	71.4	124.9	187.2	152.5	296.9	9495.9	10454.2	27.6

Appendix 18. Mean soil temperature at the soil surface during the 2001 cropping season.

DAS	10	20	27	37	52	67	82	97	112	127	Mean
D	18.7	20.3	30.6	23.1	22.4	22.6	21.4	19.7	18.2	22.0	21.9
D	18.7	20.0	28.4	23.0	23.3	22.5	21.7	19.6	17.9	22.2	21.7
D	18.0	22.8	28.8	26.7	22.0	23.8	22.0	19.8	18.0	21.9	22.4
mean	18.4	21.0	29.3	24.3	22.6	23.0	21.7	19.7	18.0	22.0	22.0
C	19.2	20.2	27.6	22.4	22.6	22.5	22.9	20.4	18.0	23.0	21.9
C	18.0	22.6	28.9	25.6	22.8	22.9	22.9	19.6	18.2	21.8	22.4
C	17.8	23.1	30.3	26.4	22.2	24.2	23.0	19.7	18.5	22.4	22.8
mean	18.3	22.0	28.9	24.8	22.5	23.2	23.0	19.9	18.3	22.4	22.3
C+P	20.9	21.7	45.1	25.3	22.8	22.4	21.3	20.3	18.2	21.7	24.0
C+P	22.1	23.4	39.5	24.4	23.3	22.6	21.7	21.4	18.0	22.4	23.9
C+P	21.2	25.6	39.6	31.2	22.0	23.5	21.5	20.1	18.2	23.2	24.6
mean	21.4	23.6	41.4	27.0	22.7	22.8	21.5	20.6	18.1	22.4	24.1
C+P+S(P)	18.4	22.8	41.0	24.8	22.4	22.1	21.4	20.3	18.3	24.4	23.6
C+P+S(P)	20.5	23.5	40.8	25.5	22.8	22.2	21.8	21.0	18.0	22.7	23.9
C+P+S(P)	21.4	24.5	43.5	28.9	22.1	24.2	23.0	20.3	18.2	23.1	24.9
mean	20.1	23.6	41.8	26.4	22.4	22.9	22.1	20.5	18.2	23.4	24.1
C+P+S(S)	16.8	18.9	27.5	22.1	20.6	21.5	21.7	19.4	17.8	20.0	20.6
C+P+S(S)	16.8	19.5	27.9	22.8	21.8	22.1	21.5	19.4	18.0	20.6	21.0
C+P+S(S)	16.4	20.3	27.8	24.0	21.2	22.1	21.7	19.3	18.4	20.1	21.1
mean	16.7	19.6	27.7	22.9	21.2	21.9	21.7	19.3	18.0	20.3	20.9
C+P+IS	20.7	22.4	44.0	25.2	22.7	22.4	21.9	20.9	18.2	22.2	24.1
C+P+IS	23.6	25.7	44.4	29.3	23.5	23.1	22.7	20.1	18.2	22.0	25.3
C+P+IS	23.5	26.9	44.5	31.5	22.5	23.8	23.3	20.2	18.4	22.7	25.7
mean	22.6	25.0	44.3	28.6	22.9	23.1	22.6	20.4	18.3	22.3	25.0

Appendix 19 Mean soil temperature at 5 cm soil depth during the 2001 cropping season.

DAS	10	20	27	37	52	67	82	97	112	127	Mean
D	17.4	18.4	22.3	20.9	20.0	20.8	19.6	19.0	18.3	20.9	19.7
D	17.8	18.5	21.4	20.8	20.1	21.2	20.0	19.2	18.2	21.1	19.8
D	17.7	19.3	23.3	21.6	21.4	21.8	19.9	19.5	18.1	22.8	20.6
mean	17.6	18.7	22.3	21.1	20.5	21.3	19.8	19.2	18.2	21.6	20.0
C	18.0	18.4	20.9	20.5	19.8	20.9	20.7	19.4	18.1	22.0	19.9
C	17.8	19.1	22.9	21.4	21.7	21.6	20.0	19.4	18.1	20.8	20.3
C	17.7	19.2	24.0	22.1	21.6	21.9	20.2	19.3	18.4	21.4	20.6
mean	17.8	18.9	22.6	21.3	21.1	21.5	20.3	19.3	18.2	21.4	20.2
C+P	18.7	19.3	28.7	21.7	20.2	20.8	19.7	19.7	18.1	20.6	20.8
C+P	20.1	19.7	27.0	21.3	20.5	21.1	19.9	19.9	18.1	20.5	20.8
C+P	19.9	19.4	27.7	22.9	21.1	21.5	19.2	19.7	18.2	21.1	21.1
mean	19.6	19.5	27.8	22.0	20.6	21.1	19.6	19.7	18.1	20.8	20.9
C+P+S(P)	18.0	19.7	25.9	21.4	19.8	20.4	19.6	19.2	17.9	20.2	20.2
C+P+S(P)	19.3	19.4	25.2	21.6	20.5	20.9	19.6	19.3	18.0	20.3	20.4
C+P+S(P)	20.2	19.7	27.3	22.0	20.7	21.3	20.0	19.1	18.4	20.0	20.9
mean	19.2	19.6	26.1	21.7	20.4	20.9	19.7	19.2	18.1	20.2	20.5
C+P+S(S)	16.7	18.3	21.9	20.9	19.6	20.4	19.8	19.1	18.0	19.3	19.4
C+P+S(S)	17.1	18.5	22.5	21.0	20.3	20.9	19.8	19.2	18.2	20.2	19.8
C+P+S(S)	16.8	18.7	22.8	20.8	20.4	20.8	19.7	19.1	18.4	19.5	19.7
mean	16.9	18.5	22.4	20.9	20.1	20.7	19.8	19.1	18.2	19.6	19.6
C+P+IS	19.0	20.5	30.2	23.0	20.5	20.8	19.8	20.0	18.1	21.2	21.3
C+P+IS	22.8	21.4	31.3	23.1	20.9	21.1	20.2	19.8	18.1	21.5	22.0
C+P+IS	22.7	20.4	29.3	23.8	21.2	22.0	20.3	20.2	18.3	21.4	22.0
mean	21.5	20.8	30.3	23.3	20.9	21.3	20.1	20.0	18.2	21.4	21.8

Appendix 20. Mean soil moisture at 6 cm soil depth during the 2001 cropping season

DAS	27	37	52	67	82	97	127	mean
D	0.30	0.33	0.37	0.28	0.34	0.36	0.33	0.33
D	0.29	0.30	0.33	0.23	0.32	0.36	0.34	0.31
D	0.25	0.28	0.34	0.22	0.34	0.31	0.27	0.29
mean	0.28	0.30	0.35	0.24	0.33	0.34	0.31	0.31
C	0.26	0.28	0.35	0.30	0.33	0.37	0.34	0.32
C	0.26	0.28	0.37	0.28	0.33	0.35	0.35	0.32
C	0.22	0.28	0.34	0.23	0.29	0.33	0.31	0.28
mean	0.25	0.28	0.35	0.27	0.32	0.35	0.33	0.31
C+P(N)			0.40	0.24	0.31	0.33	0.29	0.31
C+P(N)			0.34	0.23	0.31	0.29	0.29	0.29
C+P(N)			0.36	0.33	0.30	0.34	0.30	0.33
mean			0.37	0.27	0.30	0.32	0.29	0.31
C+P(P)	0.27	0.27	0.31	0.21	0.26	0.30	0.35	0.28
C+P(P)	0.24	0.29	0.30	0.17	0.25	0.27	0.32	0.26
C+P(P)	0.28	0.25	0.32	0.16	0.21	0.35	0.31	0.27
mean	0.26	0.27	0.31	0.18	0.24	0.31	0.33	0.27
C+P+S(N)			0.39	0.29	0.31	0.37	0.32	0.34
C+P+S(N)			0.37	0.22	0.31	0.39	0.29	0.32
C+P+S(N)			0.34	0.27	0.26	0.36	0.27	0.30
mean			0.37	0.26	0.29	0.37	0.29	0.32
C+P+S(P)	0.23	0.25	0.34	0.20	0.27	0.27	0.30	0.27
C+P+S(P)	0.20	0.22	0.33	0.20	0.23	0.31	0.33	0.26
C+P+S(P)	0.27	0.23	0.31	0.16	0.21	0.26	0.34	0.26
mean	0.24	0.24	0.33	0.19	0.24	0.28	0.32	0.26
C+P+S(S)	0.36	0.33	0.38	0.32	0.34	0.31	0.39	0.35
C+P+S(S)	0.33	0.32	0.38	0.33	0.34	0.37	0.35	0.34
C+P+S(S)	0.36	0.32	0.38	0.28	0.36	0.30	0.34	0.34
mean	0.35	0.32	0.38	0.31	0.35	0.33	0.36	0.34
C+P+IS(N)			0.37	0.28	0.31	0.32	0.21	0.30
C+P+IS(N)			0.33	0.28	0.32	0.31	0.29	0.30
C+P+IS(N)			0.37	0.34	0.30	0.37	0.29	0.33
mean			0.35	0.30	0.31	0.33	0.26	0.31
C+P+IS(P)	0.24	0.19	0.30	0.22	0.30	0.21	0.35	0.26
C+P+IS(P)	0.26	0.25	0.25	0.26	0.30	0.29	0.35	0.28
C+P+IS(P)	0.26	0.29	0.32	0.27	0.26	0.32	0.32	0.29
mean	0.25	0.25	0.29	0.25	0.29	0.28	0.34	0.28

Appendix 21 Mean soil profile probe moisture at 10 cm soil depth during the 2001 cropping season.

Treatment	10	20	27	37	52	62	67	82	112	129	140
D	0.27	0.34	0.17	0.21	0.29	0.24	0.24	0.19	0.26	0.21	0.23
D	0.18	0.20	0.17	0.19	0.26	0.24	0.24	0.23	0.31	0.24	0.27
D	0.14	0.33	0.29	0.35	0.44	0.42	0.42	0.39	0.44	0.44	0.35
C	0.21	0.19	0.24	0.18	0.26	0.26	0.26	0.21	0.24	0.38	0.41
C	0.40	0.49	0.48	0.42	0.52	0.48	0.48	0.47	0.53	0.52	0.52
C	0.21	0.25	0.24	0.23	0.32	0.29	0.29	0.30	0.39	0.36	0.34
C+P	0.27	0.26	0.31	0.23	0.28	0.24	0.24	0.32	0.38	0.27	0.35
C+P	0.19	0.32	0.19	0.21	0.26	0.20	0.20	0.24	0.34	0.26	0.26
C+P	0.24	0.29	0.33	0.24	0.27	0.23	0.23	0.28	0.28	0.28	0.35
C+P+S	0.29	0.29	0.27	0.25	0.31	0.24	0.24	0.25	0.32	0.29	0.28
C+P+S	0.24	0.25	0.31	0.29	0.39	0.26	0.26	0.30	0.29	0.38	0.39
C+P+S	0.23	0.30	0.29	0.30	0.35	0.28	0.28	0.36	0.35	0.28	0.38
C+P+IS	0.17	0.20	0.22	0.20	0.24	0.20	0.20	0.22	0.27	0.28	0.28
C+P+IS	0.29	0.32	0.32	0.34	0.29	0.25	0.25	0.28	0.32	0.32	0.34
C+P+IS	0.38	0.49	0.46	0.42	0.53	0.52	0.52	0.51	0.56	0.50	0.53

Appendix 22. Mean soil profile probe moisture at 20 cm soil depth during the 2001 cropping season.

Treatment	10	20	27	37	52	62	67	82	112	129	140
D	0.30	0.28	0.29	0.24	0.26	0.22	0.22	0.21	0.27	0.28	0.28
D	0.16	0.20	0.25	0.21	0.22	0.24	0.24	0.23	0.31	0.29	0.29
D	0.22	0.37	0.36	0.35	0.40	0.36	0.36	0.40	0.39	0.39	0.39
C	0.21	0.20	0.25	0.19	0.22	0.27	0.27	0.21	0.36	0.38	0.39
C	0.33	0.36	0.42	0.40	0.42	0.38	0.38	0.46	0.46	0.43	0.49
C	0.18	0.20	0.21	0.21	0.23	0.19	0.19	0.21	0.29	0.30	0.29
C+P	0.28	0.27	0.33	0.27	0.29	0.23	0.23	0.35	0.37	0.33	0.37
C+P	0.27	0.32	0.26	0.29	0.29	0.23	0.23	0.27	0.35	0.28	0.28
C+P	0.25	0.33	0.33	0.30	0.31	0.28	0.28	0.34	0.34	0.37	0.39
C+P+S	0.23	0.22	0.21	0.22	0.25	0.20	0.20	0.21	0.24	0.23	0.24
C+P+S	0.31	0.39	0.41	0.39	0.44	0.33	0.33	0.40	0.42	0.42	0.42
C+P+S	0.31	0.33	0.33	0.35	0.38	0.33	0.33	0.37	0.39	0.38	0.41
C+P+IS	0.21	0.23	0.23	0.24	0.24	0.19	0.19	0.24	0.27	0.26	0.24
C+P+IS	0.35	0.37	0.35	0.34	0.35	0.32	0.32	0.32	0.38	0.41	0.37
C+P+IS	0.27	0.27	0.27	0.30	0.34	0.29	0.29	0.30	0.31	0.30	0.35

Appendix 23. Mean soil profile probe moisture at 30 cm soil depth during the 2001 cropping season.

Treatment	10	20	27	37	52	62	67	82	112	129	140
D	0.32	0.33	0.34	0.28	0.32	0.26	0.26	0.32	0.35	0.35	0.37
D	0.28	0.33	0.20	0.30	0.33	0.31	0.31	0.35	0.34	0.32	0.35
D	0.23	0.34	0.31	0.29	0.37	0.30	0.30	0.33	0.37	0.37	0.46
C	0.15	0.16	0.19	0.15	0.18	0.20	0.20	0.21	0.22	0.22	0.25
C	0.29	0.34	0.31	0.29	0.35	0.34	0.34	0.33	0.36	0.33	0.33
C	0.27	0.27	0.28	0.27	0.27	0.24	0.24	0.25	0.33	0.32	0.31
C+P	0.29	0.28	0.28	0.28	0.30	0.26	0.26	0.36	0.34	0.35	0.35
C+P	0.21	0.32	0.32	0.29	0.32	0.28	0.28	0.30	0.32	0.30	0.28
C+P	0.39	0.43	0.43	0.42	0.44	0.41	0.41	0.46	0.45	0.45	0.46
C+P+S	0.30	0.33	0.34	0.36	0.38	0.32	0.32	0.39	0.38	0.34	0.36
C+P+S	0.40	0.46	0.43	0.41	0.48	0.41	0.41	0.44	0.48	0.48	0.47
C+P+S	0.29	0.31	0.31	0.30	0.35	0.31	0.31	0.34	0.35	0.35	0.35
C+P+IS	0.34	0.37	0.39	0.44	0.42	0.33	0.33	0.45	0.45	0.43	0.42
C+P+IS	0.30	0.34	0.34	0.32	0.37	0.33	0.33	0.37	0.35	0.34	0.36
C+P+IS	0.28	0.24	0.26	0.30	0.33	0.26	0.26	0.28	0.28	0.27	0.32

Appendix 24. Mean soil profile probe moisture at 40 cm soil depth during the 2001 cropping season.

Treatment	10	20	27	37	52	62	67	82	112	129	140
D	0.27	0.33	0.26	0.30	0.34	0.29	0.29	0.37	0.35	0.34	0.34
D	0.41	0.43	0.44	0.40	0.43	0.42	0.42	0.45	0.44	0.46	0.45
D	0.36	0.41	0.38	0.38	0.43	0.38	0.38	0.41	0.41	0.40	0.50
C	0.34	0.36	0.32	0.32	0.41	0.34	0.34	0.51	0.36	0.38	0.38
C	0.45	0.54	0.46	0.45	0.52	0.56	0.56	0.52	0.55	0.48	0.50
C	0.43	0.48	0.44	0.42	0.44	0.40	0.40	0.46	0.44	0.43	0.42
C+P	0.30	0.31	0.31	0.29	0.33	0.29	0.29	0.39	0.37	0.34	0.33
C+P	0.42	0.45	0.47	0.44	0.51	0.49	0.49	0.50	0.45	0.48	0.47
C+P	0.46	0.51	0.43	0.46	0.51	0.48	0.48	0.58	0.51	0.50	0.50
C+P+S	0.44	0.48	0.46	0.42	0.50	0.43	0.43	0.51	0.49	0.45	0.49
C+P+S	0.35	0.38	0.37	0.37	0.40	0.38	0.38	0.44	0.39	0.36	0.40
C+P+S	0.29	0.34	0.32	0.31	0.36	0.34	0.34	0.36	0.37	0.36	0.36
C+P+IS	0.36	0.50	0.53	0.48	0.49	0.45	0.45	0.55	0.53	0.50	0.51
C+P+IS	0.29	0.31	0.32	0.31	0.34	0.31	0.31	0.35	0.34	0.31	0.32
C+P+IS	0.29	0.28	0.27	0.29	0.32	0.30	0.30	0.32	0.29	0.29	0.31

Appendix 25. Mean soil profile probe moisture at 100 cm soil depth during the 2001 cropping season.

Treatment	10	20	27	37	52	62	67	82	112	129	140
D	0.58	0.72	0.77	0.63	0.82	0.68	0.68	0.81	0.88	0.88	0.86
D	0.22	0.21	0.24	0.25	0.24	0.28	0.28	0.26	0.28	0.25	0.22
D	0.41	0.51	0.49	0.38	0.58	0.49	0.49	0.60	0.69	0.45	0.60
C	0.31	0.33	0.37	0.36	0.38	0.39	0.39	0.40	0.40	0.41	0.40
C	0.32	0.34	0.39	0.43	0.37	0.41	0.41	0.54	0.43	0.43	0.48
C	0.32	0.59	0.57	0.53	0.65	0.63	0.63	0.82	0.55	0.54	0.71
C+P	0.39	0.48	0.43	0.44	0.54	0.49	0.49	0.46	0.48	0.46	0.46
C+P	0.52	0.47	0.70	0.61	0.64	0.76	0.76	0.59	0.63	0.60	0.60
C+P	0.68	0.69	0.55	0.78	0.59	0.88	0.88	0.80	0.88	0.88	0.60
C+P+S	0.56	0.62	0.60	0.59	0.68	0.62	0.62	0.66	0.72	0.65	0.69
C+P+S	0.23	0.30	0.25	0.25	0.27	0.37	0.37	0.27	0.36	0.30	0.35
C+P+S	0.48	0.54	0.57	0.57	0.66	0.63	0.63	0.72	0.72	0.69	0.68
C+P+IS	0.43	0.51	0.51	0.53	0.55	0.55	0.55	0.61	0.63	0.61	0.59
C+P+IS	0.66	0.68	0.73	0.71	0.83	0.53	0.53	0.78	0.69	0.57	0.65
C+P+IS	0.49	0.64	0.59	0.56	0.55	0.68	0.68	0.88	0.75	0.88	0.75

Appendix 26. Mean soil bulk density at the beginning and end of the 2001 cropping season

At the beginning of cropping season			At the end of cropping season		
Treatment	10cm	20cm	Treatment	10cm	20cm
D	1.27	1.42	D	1.33	1.22
D	1.27	1.29	D	1.31	1.30
D	1.25	1.23	D	1.25	1.28
C	1.38	1.37	C	1.23	1.23
C	1.28	1.2	C	1.30	1.25
C	1.35	1.24	C	1.33	1.28
C+P	1.26	1.36	C+P	1.29	1.15
C+P	1.25	1.24	C+P	1.21	1.12
C+P	1.18	1.22	C+P	1.22	1.27
C+P+S	1.24	1.33	C+P+S	1.22	1.22
C+P+S	1.20	1.33	C+P+S	1.23	1.20
C+P+S	1.25	1.39	C+P+S	1.28	1.20
C+P+IS	1.20	1.38	C+P+IS	0.99	1.31
C+P+IS	1.19	1.35	C+P+IS	1.02	1.22
C+P+IS	1.19	1.3	C+P+IS	1.07	1.23

Appendix 27 Soil chemical analysis at the beginning of 2001.

Treatment	N %	Avail. P	K %	P %	O.M%	K (ppm)	Avail. N (ppm)	pH
D(T)	0.09	39.49	1.49	0.11	1.08	98.20	146.17	5.22
D(T)	0.09	31.78	2.77	0.08	1.00	132.40	140.66	4.40
D(T)	0.09	45.57	2.34	0.09	1.07	114.10	140.66	5.12
C(T)	0.11	20.83	2.56	0.10	1.05	126.10	132.38	5.70
C(T)	0.10	35.48	2.23	0.10	1.17	154.80	148.19	5.51
C(T)	0.10	46.62	1.66	0.12	1.30	66.70	134.47	5.83
C+P(T)	0.09	38.58	2.15	0.12	1.14	138.90	154.45	5.70
C+P(T)	0.11	39.41	2.65	0.11	1.24	110.80	146.17	5.34
C+P(T)	0.09	30.61	2.11	0.10	1.10	133.90	132.38	5.12
C+P+S(T)	0.10	35.73	1.79	0.11	1.14	180.80	133.42	5.18
C+P+S(T)	0.10	38.30	2.49	0.10	1.19	117.20	143.42	5.14
C+P+S(T)	0.07	38.29	2.10	0.11	1.17	96.34	143.42	5.53
C+P+IS(T)	0.10	29.16	1.51	0.11	1.25	116.40	132.38	5.19
C+P+IS(T)	0.10	44.14	2.11	0.11	0.92	112.30	150.31	5.46
C+P+IS(T)	0.08	33.18	2.25	0.11	1.19	152.60	183.87	5.44
D(B)	0.10	23.64	1.98	0.09	1.10	99.80	123.80	5.09
D(B)	0.12	39.37	2.25	0.11	1.10	96.23	159.96	4.32
D(B)	0.09	31.80	1.78	0.10	1.13	89.34	151.32	5.50
C(B)	0.07	13.30	2.45	0.09	1.09	104.40	165.48	5.50
C(B)	0.09	38.29	1.85	0.10	1.17	101.90	124.11	5.52
C(B)	0.10	38.35	1.53	0.11	1.37	72.42	143.42	5.94
C+P(B)	0.12	30.05	1.78	0.09	1.18	126.00	148.93	5.25
C+P(B)	0.09	40.55	2.34	0.12	1.08	103.30	121.35	5.36
C+P(B)	0.09	30.12	1.77	0.11	1.06	78.04	115.84	5.46
C+P+S(B)	0.10	25.26	1.61	0.08	1.15	112.40	126.24	5.00
C+P+S(B)	0.12	29.12	2.18	0.10	1.16	77.09	132.38	5.33
C+P+S(B)	0.11	39.04	2.09	0.09	1.16	88.35	145.45	5.66
C+P+IS(B)	0.05	21.73	1.60	0.07	1.10	104.30	134.47	5.12
C+P+IS(B)	0.10	32.38	2.14	0.10	1.06	66.36	114.46	5.62
C+P+IS(B)	0.09	43.28	1.84	0.10	1.11	81.96	132.38	5.26
D(M)	0.06	32.37	2.15	0.11	1.09	112.30	133.76	5.22
D(M)	0.13	39.28	2.81	0.12	1.23	121.30	137.90	4.80
D(M)	0.09	40.30	1.92	0.10	1.15	122.90	146.17	5.39
C(M)	0.10	18.59	2.50	0.11	1.16	151.70	154.45	5.37
C(M)	0.08	34.38	2.09	0.10	1.15	114.70	146.17	5.55
C(M)	0.11	43.17	1.50	0.13	1.29	64.22	151.69	5.98
C+P(M)	0.11	34.28	1.82	0.09	1.14	138.60	158.38	5.37
C+P(M)	0.11	42.75	2.53	0.12	1.17	107.40	146.17	5.33
C+P(M)	0.09	40.27	1.86	0.10	0.99	96.34	131.73	5.45
C+P+S(M)	0.08	25.38	1.49	0.08	1.10	128.40	151.69	5.17
C+P+S(M)	0.09	37.07	2.42	0.11	0.99	101.80	115.84	5.60
C+P+S(M)	0.08	37.01	2.15	0.10	1.12	96.19	146.82	5.58
C+P+IS(M)	0.12	28.91	1.32	0.09	1.23	134.90	158.20	4.84
C+P+IS(M)	0.08	38.26	2.55	0.16	1.06	118.20	148.93	5.36
C+P+IS(M)	0.10	45.44	1.92	0.11	1.17	112.50	138.25	5.57

(T)- Samples from plot top position, (B)- Samples from plot bottom position and (M) Mixture plot samples

Appendix 28 Soil chemical analysis at the end of 2001.

Treatment	N %	Avail. P	K %	P %	O.M %	K(ppm)	Avail. N (ppm)	pH
D	0.09	14.08	1.56	0.07	1.50	56.16	107.20	5.00
D	0.10	21.33	2.51	0.03	1.30	52.50	101.96	4.80
D	0.09	15.90	2.54	0.05	1.20	72.21	115.40	5.10
C	0.10	9.59	2.30	0.03	1.40	71.36	85.27	5.30
C	0.01	12.25	2.83	0.05	1.18	103.78	107.28	4.90
C	0.10	17.19	2.26	0.06	1.15	44.25	87.94	5.30
C+P (P)	0.12	10.53	1.78	0.02	1.33	65.84	132.03	5.00
C+P (P)	0.10	18.27	2.15	0.03	1.24	48.41	109.96	5.30
C+P (P)	0.11	18.53	3.01	0.08	1.14	106.90	104.45	5.40
C+P (R)	0.10	6.75	1.77	0.05	1.29	60.14	101.82	5.12
C+P (R)	0.08	13.55	2.49	0.04	1.51	54.49	93.60	5.40
C+P (R)	0.08	11.14	2.44	0.06	1.13	67.96	99.25	5.20
C+P+S (P)	0.10	14.68	1.95	0.04	1.35	107.33	123.92	5.00
C+P+S (P)	0.10	15.18	2.67	0.04	1.32	80.02	107.54	5.40
C+P+S (P)	0.09	16.83	2.91	0.04	1.20	87.62	102.11	5.20
C+P+S (S)	0.11	19.22	1.94	0.02	1.60	150.49	112.13	5.20
C+P+S (S)	0.10	13.64	2.38	0.05	1.40	83.50	121.10	5.50
C+P+S (S)	0.09	11.25	3.12	0.05	1.04	87.97	96.21	5.40
C+P+IS (P)	0.14	10.26	1.96	0.03	1.64	87.28	151.26	5.00
C+P+IS (P)	0.10	11.10	3.58	0.06	1.23	44.16	100.48	5.20
C+P+IS (P)	0.09	10.17	2.72	0.02	1.07	72.50	107.27	4.90
C+P+IS (S)	0.11	10.73	2.03	0.03	1.45	92.13	135.10	5.20
C+P+IS (S)	0.09	16.09	2.95	0.07	1.08	63.86	98.84	5.50
C+P+IS (S)	0.09	14.56	2.74	0.05	1.16	71.50	90.93	5.10

(p)-under polythene, (R)-between rows, (S)-under straw for C+P+S and under soybean rows for C+P+IS

Appendix 29. Mean plant height during the 2000 cropping season.

Treatment	20D	40D	55D	70D	85D	100D
D	7.3	23.6	57.3	120.1	233.3	225.3
D	6.4	18.9	47.1	102.4	225.0	202.8
D	6.4	22.2	60.0	125.5	227.0	218.3
C	7.5	23.8	51.9	103.9	216.8	207.9
C	6.7	24.3	58.8	129.0	240.4	234.3
C	6.7	28.8	64.4	130.9	234.8	232.5
C+P	9.3	34.1	85.8	158.9	243.1	242.1
C+P	9.1	32.7	81.6	157.0	254.6	253.3
C+P	9.1	27.9	73.4	147.9	247.5	247.9
C+P+S	9.3	32.0	75.1	147.6	245.4	244.9
C+P+S	9.7	33.1	86.6	162.4	254.5	252.4
C+P+S	9.1	25.8	75.3	145.3	250.6	253.5
C+P+IS	9.8	33.4	79.8	153.9	245.0	240.1
C+P+IS	9.1	36.0	88.0	163.8	248.5	249.3
C+P+IS	8.9	29.7	75.0	153.5	242.5	244.5

Appendix 30. Mean Green Leaf Area Index during the 2001 cropping season.

Treatment	40D	55D	70D	85D	100D
D	0.26	1.26	3.02	1.93	1.47
D	0.14	0.79	2.30	1.73	1.38
D	0.17	1.06	2.92	2.21	1.83
C	0.15	0.94	2.40	1.86	1.35
C	0.18	1.24	3.35	1.96	1.82
C	0.21	1.48	3.39	2.52	1.71
C+P	0.44	2.14	3.61	2.11	1.72
C+P	0.38	2.34	4.30	2.57	1.87
C+P	0.35	1.76	3.75	2.40	2.03
C+P+S	0.41	1.56	3.49	2.36	1.19
C+P+S	0.51	2.31	4.47	2.79	2.15
C+P+S	0.36	1.95	3.89	2.25	1.63
C+P+IS	0.43	1.97	3.38	1.85	1.38
C+P+IS	0.40	2.29	4.15	2.27	1.85
C+P+IS	0.27	1.92	3.70	2.20	1.88

Appendix 31. Mean harvest parameters in 2001.

Treatment	Stem Girth (cm)	Cob Length (cm)	Cob Girth (cm)	W. Fresh cob (g)	W. Fresh stem (g)	Grain no. of two columns	W. Dry stem (g)	W. Dry cob (g)	W. Dry grain (g)	W.1000grain (g)	Yield1 (kg/ha)	Yield2 (kg/ha)	Leaf stem (T)
D	6.4	14.9	16.4	254.9	430.3	56.0	96.9	126.7	101.2	242.0	6369.8	6940.6	25.1
D	5.1	13.1	15.8	218.2	359.8	55.0	89.0	117.4	87.5	226.6	6207.1	5994.2	23.6
D	6.3	14.1	17.4	260.8	433.4	54.0	82.0	128.7	98.6	241.7	6064.7	6764.7	27.5
C	6.0	13.1	16.5	226.2	361.5	52.0	92.0	115.8	89.0	212.8	6452.9	6097.3	24.6
C	5.8	14.4	16.2	256.3	474.3	58.0	99.2	126.1	100.5	236.1	7103.7	6886.0	29.9
C	6.7	15.1	17.4	275.6	444.8	59.0	99.0	136.7	108.6	246.6	6425.7	7444.2	26.2
C+P	6.8	13.9	16.9	253.3	426.7	57.0	99.1	142.5	108.1	282.9	8185.2	7407.8	28.5
C+P	6.8	15.7	17.3	316.0	522.7	61.0	123.4	162.9	132.7	291.4	8434.3	9100.5	31.7
C+P	7.0	15.5	17.8	294.2	563.0	61.0	112.3	155.6	123.1	273.7	8203.8	8439.2	33.2
C+P+S	6.3	14.6	16.7	287.4	424.3	60.0	90.9	158.2	124.5	258.1	7763.1	8530.2	27.3
C+P+S	7.3	15.9	18.3	354.2	598.6	65.0	141.5	192.2	151.1	312.4	9198.8	10356.3	31.3
C+P+S	7.1	15.9	17.4	293.6	532.6	60.0	100.0	151.7	121.4	276.9	8305.5	8323.9	32.4
C+P+IS	6.4	14.1	16.5	263.0	378.1	60.0	92.3	142.3	112.2	258.2	8603.8	7692.9	28.3
C+P+IS	5.7	15.1	17.3	301.8	463.5	61.0	112.8	161.5	130.3	279.4	9405.6	8930.6	34.2
C+P+IS	6.1	15.1	17.2	297.2	532.6	57.0	141.4	154.2	120.8	272.7	8046.2	8281.4	32.8

Appendix 32 Mean sensor soil temperature during the 2001 cropping season (1, 5 and10 mean 1,5 and 10 cm soil depth
s-under straw mulch and p-under polythene mulch, - data lost)

DELTA-T LOGGER												
Treatment	C+P+S5s	C+P+S1p	C+P+S5p	C+P+S10p	C+P5p	D5	C5	C+P5p	C5	C5	C+P5p	C+P+S1s
20/05/01	18.72	23.44	22.24	20.95	24.50	18.69	18.64	23.91	18.83	18.92	20.91	18.31
21/05/01	18.04	22.05	20.92	20.54	23.68	18.01	17.93	22.95	18.07	18.52	20.72	17.88
22/05/01	17.30	19.93	19.31	19.28	21.38	17.33	17.26	20.67	17.39	17.76	19.27	17.36
23/05/01	18.84	22.33	20.98	20.39	23.57	18.51	18.54	22.88	18.36	18.98	20.43	18.65
24/05/01	19.32	23.49	22.34	21.65	24.38	19.06	19.21	23.66	18.52	18.86	21.06	18.91
25/05/01	16.90	20.18	19.42	19.61	21.00	17.20	17.13	21.01	16.98	17.45	19.47	16.84
26/05/01	15.60	17.74	17.34	18.03	17.71	15.96	15.87	18.69	15.60	16.09	17.82	15.53
29/05/01	16.89	19.83	18.85	17.95	19.63	16.81	16.86	20.54	16.75	17.37	18.27	16.80
30/05/01	16.14	18.57	18.41	17.80	18.93	16.24	16.21	20.05	16.07	16.60	18.16	16.11
31/05/01	14.92	16.15	16.45	16.71	16.68	15.24	15.14	17.52	14.88	15.35	16.80	14.85
01/06/01	14.08	15.61	15.60	15.56	15.84	14.53	14.51	16.76	14.34	14.90	15.76	14.08
02/06/01	14.59	15.98	15.78	15.68	16.19	14.92	14.87	16.74	14.83	15.26	15.80	14.62
03/06/01	16.89	19.59	18.53	17.72	18.60	16.85	16.85	19.81	16.86	17.42	17.98	16.81
04/06/01	18.22	21.49	20.30	19.22	18.28	18.07	18.14	21.14	17.65	18.43	18.86	17.89
05/06/01	17.68	19.82	19.32	19.05	17.98	17.84	17.76	19.94	17.38	18.05	18.49	17.54
06/06/01	18.07	20.27	19.40	18.83	18.45	18.09	18.02	19.78	18.04	18.52	18.55	17.98
07/06/01	19.51	22.13	21.92	20.33	19.91	19.43	19.31	21.07	19.23	19.75	20.17	19.34
08/06/01	19.63	22.93	22.53	21.27	20.36	19.70	19.48	21.74	19.48	19.76	20.97	19.37
09/06/01	20.27	23.83	23.22	21.99	21.27	20.39	20.11	22.77	20.17	20.28	21.55	20.01
10/06/01	19.78	23.70	23.70	22.07	21.01	20.43	20.14	23.06	20.67	20.64	22.09	19.76
11/06/01	19.24	20.71	21.01	20.66	19.79	19.21	19.16	21.01	19.20	19.63	20.45	19.23
12/06/01	17.96	18.93	19.25	19.27	17.79	18.04	17.95	18.99	18.09	18.61	19.14	17.94
13/06/01	19.20	22.34	22.01	20.19	19.05	19.03	18.99	20.72	18.64	19.55	20.08	18.98
14/06/01	20.23	24.06	23.58	22.07	20.56	19.97	20.02	22.62	18.72	20.02	21.36	19.92
15/06/01	20.61	24.62	24.10	22.90	21.46	20.62	20.70	23.61	19.18	20.25	21.93	20.35
16/06/01	21.40	25.31	24.57	23.39	22.39	21.29	21.36	24.50	19.98	21.20	22.66	21.26
17/06/01	21.17	24.44	24.22	23.18	22.32	21.20	21.26	24.01	20.38	21.22	22.73	21.05
18/06/01	21.12	24.56	24.17	22.98	22.20	21.10	21.23	24.00	20.41	21.21	22.75	21.06
19/06/01	21.99	25.36	25.00	23.62	22.37	21.80	22.00	24.95	20.95	22.02	23.46	21.96
20/06/01	18.85	19.73	20.29	20.51	17.82	18.57	18.84	19.68	18.31	19.28	19.49	18.83
21/06/01	17.50	18.10	18.36	18.79	17.01	17.51	17.45	18.28	17.25	17.88	18.41	17.55
22/06/01	18.72	20.27	20.26	19.40	18.30	18.31	18.42	19.51	18.00	19.14	19.10	18.91
23/06/01	19.79	21.64	21.54	20.62	19.74	19.40	19.42	20.55	19.03	20.06	20.05	19.98
24/06/01	20.03	21.35	21.15	20.72	19.74	19.66	19.63	20.56	19.63	20.23	20.30	20.25
25/06/01	21.55	22.83	22.28	21.48	20.70	20.69	20.56	21.53	20.83	21.36	21.12	21.93
26/06/01	20.26	21.26	20.83	20.83	19.11	19.67	19.86	20.42	19.63	20.41	19.97	20.51
27/06/01	20.32	21.08	20.97	20.69	20.03	20.20	20.07	20.62	19.94	20.47	20.35	20.59
28/06/01	20.77	21.78	21.68	20.99	20.13	20.47	20.38	20.90	20.26	20.93	20.74	21.13
29/06/01	19.87	20.83	20.99	20.67	19.12	19.86	19.86	20.29	19.57	20.33	20.63	20.16

treatment	C+P+S5s	C+P+S1p	C+P+S5p	C+P+S10p	C+P5p	D5	C5	C+P5p	C5	C5	C+P5p	C+P+S1s
30/06/01	19.81	20.39	20.26	19.96	19.03	19.44	19.42	19.70	19.32	19.92	19.97	20.18
01/07/01	21.05	21.98	21.69	21.03	19.83	20.34	20.35	20.86	20.19	21.09	20.79	21.42
02/07/01	19.29	19.84	19.84	19.95	18.49	19.24	19.22	19.54	18.91	19.62	19.55	19.56
03/07/01	18.53	19.22	19.27	19.32	18.45	18.83	18.71	19.03	18.75	19.03	19.23	18.68
04/07/01	18.04	18.85	18.92	18.86	17.82	18.25	18.28	18.56	18.42	18.65	19.00	18.13
05/07/01	19.52	20.67	20.57	19.62	18.73	18.97	19.27	19.63	20.23	20.04	19.78	19.65
06/07/01	20.44	21.84	21.71	20.70	19.70	19.89	20.17	20.56	20.69	20.80	20.66	20.53
07/07/01	18.78	19.60	19.75	19.81	19.02	19.05	19.11	19.37	19.14	19.18	19.83	18.85
08/07/01	17.79	18.10	18.21	18.60	17.61	18.23	18.22	18.22	17.79	18.20	18.72	17.87
09/07/01	18.77	19.29	19.28	18.82	18.40	18.49	18.65	18.76	18.84	19.06	18.90	18.85
10/07/01	20.39	20.76	20.66	19.94	19.56	19.66	19.94	20.05	19.99	20.32	19.87	20.50
11/07/01	20.68	21.45	21.26	20.55	19.94	20.12	20.39	20.39	19.46	20.69	20.26	20.77
12/07/01	20.95	22.06	21.71	21.13	20.00	20.38	20.73	20.73	19.63	21.17	20.78	20.95
13/07/01	20.02	20.38	20.41	20.34	18.88	19.92	20.08	19.69	19.75	20.30	20.44	20.12
14/07/01	19.52	20.46	20.47	20.01	19.08	19.53	19.84	19.51	19.93	20.20	20.33	19.56
15/07/01	18.94	19.60	19.64	19.55	18.79	19.14	19.44	19.19	19.40	19.58	19.89	18.99
16/07/01	19.44	20.04	20.00	19.70	19.35	19.47	19.69	19.48	19.71	19.89	20.08	19.51
17/07/01	19.98	20.76	20.56	20.16	19.29	19.84	20.03	19.80	19.93	20.34	20.34	20.05
18/07/01	19.55	20.03	19.94	19.88	18.78	19.61	19.65	19.38	19.38	19.81	20.07	19.61
19/07/01	19.08	19.82	19.74	19.51	18.73	19.27	19.41	18.99	19.36	19.56	21.06	19.06
20/07/01	19.41	20.43	20.54	19.87	19.10	19.54	19.87	19.40	19.73	20.27	21.72	19.31
21/07/01	18.45	19.71	19.77	19.55	18.96	19.13	19.42	19.13	19.23	19.61	21.64	18.29
22/07/01	19.48	20.13	20.19	19.61	19.11	19.18	19.49	19.38	19.35	19.93	21.42	19.37
23/07/01	18.78	19.52	19.63	19.50	18.96	19.23	19.45	19.31	19.06	19.64	21.08	18.78
24/07/01	19.85	20.42	20.41	19.72	19.22	19.53	19.83	19.63	19.71	20.35	21.36	19.82
25/07/01	19.39	19.97	19.93	19.74	19.04	19.48	19.59	19.52	19.42	19.98	20.38	19.39
26/07/01	19.37	19.68	19.56	19.34	19.04	19.34	19.48	19.36	19.45	19.70	20.13	19.43
27/07/01	20.08	20.53	20.59	19.90	19.33	19.93	20.15	19.95	20.07	20.49	21.28	20.17
28/07/01	19.23	19.44	19.56	19.54	18.64	19.45	19.63	19.39	19.36	19.83	20.04	19.29
29/07/01	19.19	19.38	19.49	19.26	19.15	19.34	19.50	19.37	19.43	19.65	20.27	19.28
30/07/01	19.40	19.40	19.46	19.16	18.88	19.14	19.34	19.23	19.30	19.62	19.75	-
31/07/01	18.66	18.91	19.02	19.08	18.82	19.02	19.19	19.07	19.00	19.25	19.66	-
01/08/01	18.60	19.13	19.13	18.89	18.55	18.72	19.02	18.89	18.99	19.28	20.09	-
02/08/01	18.37	19.22	19.17	18.97	18.23	18.48	18.63	18.75	18.92	19.34	20.62	-
03/08/01	17.77	18.67	18.74	18.55	17.72	17.92	18.06	18.25	18.33	18.78	20.45	-
04/08/01	17.86	18.44	18.53	18.43	18.01	17.94	18.16	18.30	18.26	18.51	20.03	-
05/08/01	18.39	18.81	18.86	18.61	18.45	18.41	18.60	18.61	18.61	18.83	19.85	-
06/08/01	19.48	19.93	19.83	19.29	18.94	19.18	19.26	19.22	19.30	19.67	20.82	-
07/08/01	19.55	20.17	20.11	19.74	19.19	19.44	19.40	19.50	19.40	19.90	21.35	-
08/08/01	17.76	-	-	-	17.31	16.97	-	-	17.99	-	-	-
09/08/01	17.59	-	-	-	17.04	17.02	-	-	17.67	-	-	-
10/08/01	18.20	-	-	-	17.58	18.02	-	-	18.19	-	-	-
11/08/01	18.31	-	-	-	18.04	18.45	-	-	18.59	-	-	-
12/08/01	18.26	-	-	-	18.21	18.50	-	-	18.54	-	-	-

treatment	C+P+S5s	C+P+S1p	C+P+S5p	C+P+S10p	C+P5p	D5	C5	C+P5p	C5	C5	C+P5p	C+P+S1s
13/08/01	18.38	-	-	-	17.96	18.47	-	-	18.64	-	-	-
14/08/01	17.69	-	-	-	17.33	17.62	-	-	17.80	-	-	-
15/08/01	18.74	-	-	-	17.99	18.67	-	-	18.77	-	-	-
16/08/01	19.08	-	-	-	18.56	19.18	-	-	19.24	-	-	-
17/08/01	18.41	-	-	-	18.61	18.88	-	-	18.74	-	-	-
18/08/01	18.09	-	-	-	18.11	18.24	-	-	18.10	-	-	-
19/08/01	19.24	19.21	19.04	18.79	18.66	18.95	19.03	18.93	19.03	19.28	19.66	-
20/08/01	18.80	18.76	18.77	18.85	18.16	18.93	18.96	18.86	18.75	19.11	19.57	-
21/08/01	18.95	18.91	18.83	18.74	18.55	18.86	18.93	18.81	18.81	19.06	19.54	-
22/08/01	19.31	19.17	19.10	19.03	18.67	19.12	19.12	19.07	18.95	19.36	19.69	-
23/08/01	18.43	18.46	18.33	18.52	17.94	18.56	18.67	18.57	18.43	18.83	19.28	-
24/08/01	19.59	19.63	19.38	19.14	18.84	19.44	19.55	19.35	19.33	19.79	20.16	-
25/08/01	17.28	17.67	17.55	18.31	17.69	18.17	18.24	18.06	17.87	18.31	19.07	-
26/08/01	17.10	17.19	17.13	17.46	17.19	17.38	17.47	17.36	17.10	17.58	18.13	-
27/08/01	17.65	17.76	17.79	17.74	17.42	17.74	17.87	17.73	17.63	18.03	18.53	-
28/08/01	17.52	17.80	17.82	17.81	17.42	17.76	17.90	17.76	17.67	18.21	18.74	-
29/08/01	17.89	18.14	18.14	18.01	17.67	18.08	18.12	18.01	17.92	18.47	19.05	-
30/08/01	18.75	19.08	19.03	18.74	18.42	18.86	18.91	18.83	18.64	19.27	19.96	-
31/08/01	18.34	18.77	18.81	18.71	18.34	18.65	18.74	18.69	18.43	19.00	20.25	-
01/09/01	17.81	18.21	18.28	18.30	17.95	18.10	18.22	18.22	17.89	18.39	19.43	-
02/09/01	17.29	17.76	17.84	17.91	17.50	17.65	17.82	17.81	17.51	17.96	18.89	-
03/09/01	17.38	17.80	17.84	17.80	17.41	17.60	17.78	17.77	17.50	17.99	18.78	-
04/09/01	17.20	17.59	17.59	17.62	17.19	17.48	17.59	17.63	17.28	17.85	18.60	-
05/09/01	17.37	17.92	17.80	17.71	17.29	17.58	17.69	17.73	17.47	18.00	18.73	-
06/09/01	17.75	18.23	18.14	17.96	17.68	17.88	18.02	18.05	17.75	18.26	18.87	-
07/09/01	19.02	19.28	19.03	18.58	18.35	18.73	18.87	18.84	18.47	19.29	19.37	-
08/09/01	17.78	18.31	18.23	18.43	17.56	18.22	18.40	18.32	17.85	18.49	18.91	-
09/09/01	16.34	16.85	16.76	17.18	16.59	16.92	17.08	16.95	16.60	17.07	17.74	-
10/09/01	16.38	17.01	16.77	16.92	16.32	16.71	16.93	16.78	16.58	17.08	17.85	-
11/09/01	17.35	17.75	17.52	17.34	16.98	17.30	17.52	17.43	17.25	17.76	18.19	-
12/09/01	17.86	18.25	18.04	17.83	17.58	17.87	18.07	17.98	17.82	18.25	18.55	-
13/09/01	18.26	18.68	18.44	18.20	17.99	18.27	18.46	18.38	18.17	18.70	18.85	-
14/09/01	18.33	18.77	18.53	18.44	17.90	18.44	18.61	18.53	18.14	18.80	19.00	-
15/09/01	17.74	18.14	17.96	17.99	17.57	17.89	18.09	18.01	17.69	18.18	18.43	-
16/09/01	17.51	17.82	17.68	17.77	17.01	17.63	17.84	17.73	17.26	17.92	18.17	-
17/09/01	17.82	18.22	17.86	17.86	17.39	17.89	18.00	17.92	17.64	18.21	18.47	-
18/09/01	17.85	18.37	17.83	18.04	17.30	18.02	18.15	18.11	17.61	18.45	18.63	-
19/09/01	17.63	18.09	17.72	17.89	17.39	17.81	17.97	17.93	17.60	18.16	18.45	-
20/09/01	17.44	18.00	17.63	17.80	16.69	17.64	17.72	17.74	17.33	18.16	18.25	-
21/09/01	17.37	17.92	17.59	17.76	16.96	17.60	17.79	17.73	17.47	18.10	18.29	-
22/09/01	17.38	18.06	17.52	18.01	16.73	17.45	17.64	17.60	17.19	17.97	17.96	-
23/09/01	17.02	17.81	17.41	17.97	16.98	17.42	17.64	17.54	17.36	17.85	18.11	-
24/09/01	17.53	18.34	17.78	18.19	17.23	17.71	17.93	17.79	17.64	18.15	18.46	-
25/09/01	17.98	18.80	18.14	18.61	17.55	18.14	18.25	18.16	17.97	18.64	19.00	-

treatment	C+P+S5s	C+P+S1p	C+P+S5p	C+P+S10p	C+P5p	D5	C5	C+P5p	C5	C5	C+P5p	C+P+S1s
26/09/01	17.88	18.60	18.12	18.64	17.65	18.09	18.23	18.12	17.80	18.48	19.04	-
27/09/01	17.28	18.03	17.58	18.29	17.03	17.57	17.88	17.69	17.33	18.00	18.69	-
28/09/01	17.53	18.42	17.73	18.32	17.23	17.76	18.14	17.89	17.59	18.29	19.05	-
29/09/01	17.79	18.74	17.94	18.60	17.46	17.99	18.37	18.14	17.74	18.64	19.36	-
30/09/01	15.86	17.06	16.61	17.76	15.81	16.62	17.28	16.97	16.75	17.22	18.35	-
01/10/01	15.71	16.61	16.13	17.01	15.72	16.07	16.83	16.39	16.12	16.62	17.63	-
02/10/01	15.90	16.66	16.21	16.93	15.91	16.18	16.96	16.36	15.99	16.57	17.46	-
03/10/01	14.06	15.00	14.78	16.08	14.01	14.89	15.85	15.12	14.84	15.36	16.57	-
04/10/01	13.67	14.34	14.08	15.09	13.71	14.14	15.07	14.31	14.05	14.46	15.68	-
05/10/01	14.67	15.29	14.91	15.55	14.46	14.77	15.61	14.91	14.60	15.10	16.11	-
06/10/01	16.00	16.72	16.26	16.52	15.46	15.85	16.67	15.92	15.68	16.37	17.17	-